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A New Continuous Type Electric Furnace

Designed for the Heat-Treatment of Small and Medium-Sized Brass Pressings and Light Components

By J. McDonald

A new design of heat-treatment furnace is described which, in service, is claimed to have the following advantages: Total elimination of non-productive weight with consequent saving in power consumption; simplicity of construction and method of handling; comparatively low initial cost; and unlimited field of application. The reciprocating tray type with recuperation described represents a definite advance.

REVIEWING the progress of developments in electric heat-treatment furnaces since the beginning of the war the results are not altogether gratifying if full consideration is given to the excellent opportunities afforded in the increased demand for furnaces for specific war purposes. The limited number of skilled designers available for this type of work is, no doubt, partly responsible for the lack of development work carried out in this country, little or no time having been available for the exploration of obvious possibilities. A policy of adherence to existing methods and ideas if adopted, however, is, in the writer's opinion, detrimental to scientific progress. Exploitation of the very few war-time furnace developments already in successful operation is, of course, another matter and definitely advocated.

General standardisation of large electric furnaces is difficult in view of the rapid and ever-increasing change in heat-treatment specifications, but there are certain types of continuous furnaces, for example, in which the means of conveying have remained the same for many years without, it would seem, any serious attempt by the designer to secure increased efficiency.

The reciprocating tray furnace with recuperation, recently marketed by G.W.B. Electric Furnaces, Ltd., represents a definite advance in this direction, however, and has aroused considerable interest among the manufacturers of small and medium-sized brass pressings and light components. Mass productive heat-treatment is essential in such work and the initial work for war purposes has tremendously increased its interest. This furnace, now generally referred to as the "Shaker," was designed to fulfill these conditions and large numbers will shortly be in commission throughout the country.

Ingeniously devised, the principle employed for conveying on a dead level tray is the adoption to a furnace of the rudimentary principle of the parallel link motion. The method of conveying the charge is accomplished by transferring the oscillating movement of a crank to the furnace tray. Fundamentally, the motion will move any shape of component, but for consistent movement and complete control of specific shapes, the sectional shape of the tray is of extreme importance. Following exhaustive tests on the first plant, built twelve months ago for experimental purposes, valuable information has been obtained and is now the subject matter of patents.

The work upon which the majority of these furnaces is engaged requires cleaning, and each unit installed is complete with an automatic washing and pickling equipment. Limitation of space does not allow for reproductions of drawings showing the numerous applications of the "Shaker," but by studying the three illustrations the possibilities of the design are obvious.

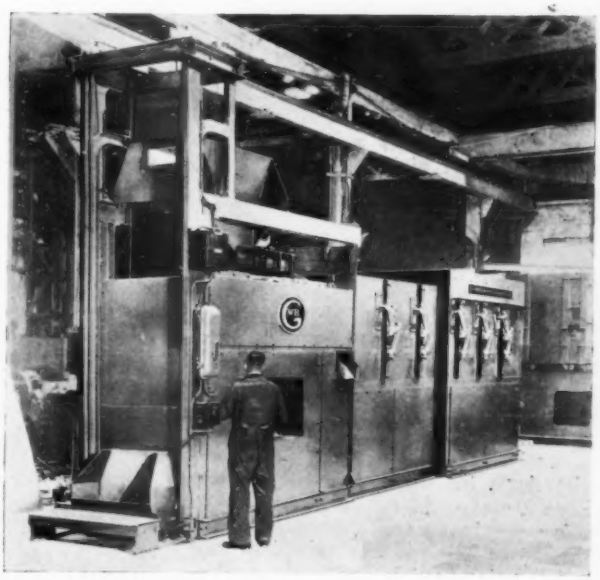


Fig. 1.—Recuperative annealing "Shaker" furnace.

According to the specified requirements, the speed of travel may vary between 2 ft. per min. and 10 ft. in 2 hours. Whatever the speed may be, the charge will flow through the furnace in a consistent, even mass and emerge with rhythmic precision. The utilisation of the simple inclined link principle for supporting the tray outside the furnace, maintains the level of the tray in both hot and cold furnace conditions. A characteristic of the movement is the very small stroke required, and the advantage of this is no doubt significant to the mechanically minded furnace engineer. An additional feature is the total exposure of the work to the true furnace temperature. Unlike the rotary drum type furnace, in which the work is totally enclosed, a charge on the "Shaker" tray is more susceptible to natural convection, and the advantages of forced convection by use of fans can be obtained, as shown on the

Fig. 2.—View of tubular cases passing through recuperation chamber.

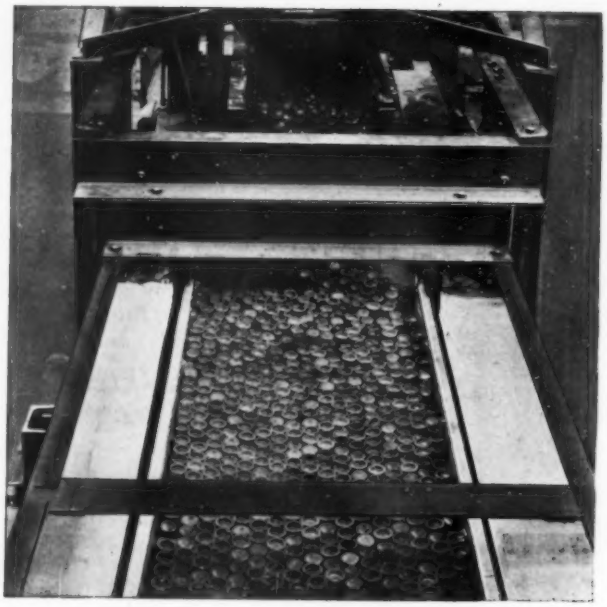


Fig. 3.—View of charge comprising small cups passing through recuperation chamber.

sketch of the single tray type of furnace. In practically all respects the " Shaker " furnace fulfills the essential requires ments for a uniform, consistent, and cheap method of heating. Previous attempts to combine these features in commercially exploited furnaces have been most elusive, and this furnace is the outcome of patient and judicious designing.

Recuperative Annealing " Shaker " Furnace

In addition to the claims already specified, recuperation further augments the high standard of efficiency. The recuperative " Shaker " furnace, large numbers of which are already in course of construction, includes automatic feeding and pickling equipment. The illustration shows the furnace in sections with a separate tray for incoming and outgoing work. Both movements are synchronised by a camshaft, ensuring a consistent speed of travel in both directions. Moving parts in the furnace have been avoided, frictional losses being eliminated and the supporting shafts are located, and swivel, in the inclined links outside the casing. The principle of the movement requires only a very small throw on the crank and the momentum on the trays is reduced to a minimum, wear and tear, therefore, being negligible.

A simple electrical hoisting bucket discharges the work into the hopper, which is provided with an infinitely-variable automatic feeding mechanism of robust design. This latter comprises a vibrating tray extending from under the hopper to the furnace tray. The high-frequency vibrating motion is obtained by an interrupted electric supply assisted by heavy springs, the equipment including a metal rectifier, double-pole switch and control rheostat. The current consumption is approximately 1 amp. and the feed obtained is very even, with a complete absence of any tendency to jam the charge in the mouth of the hopper. By means of the rheostat the rate of feed is adjusted

Fig. 6.—Reciprocating tray hardening furnace.

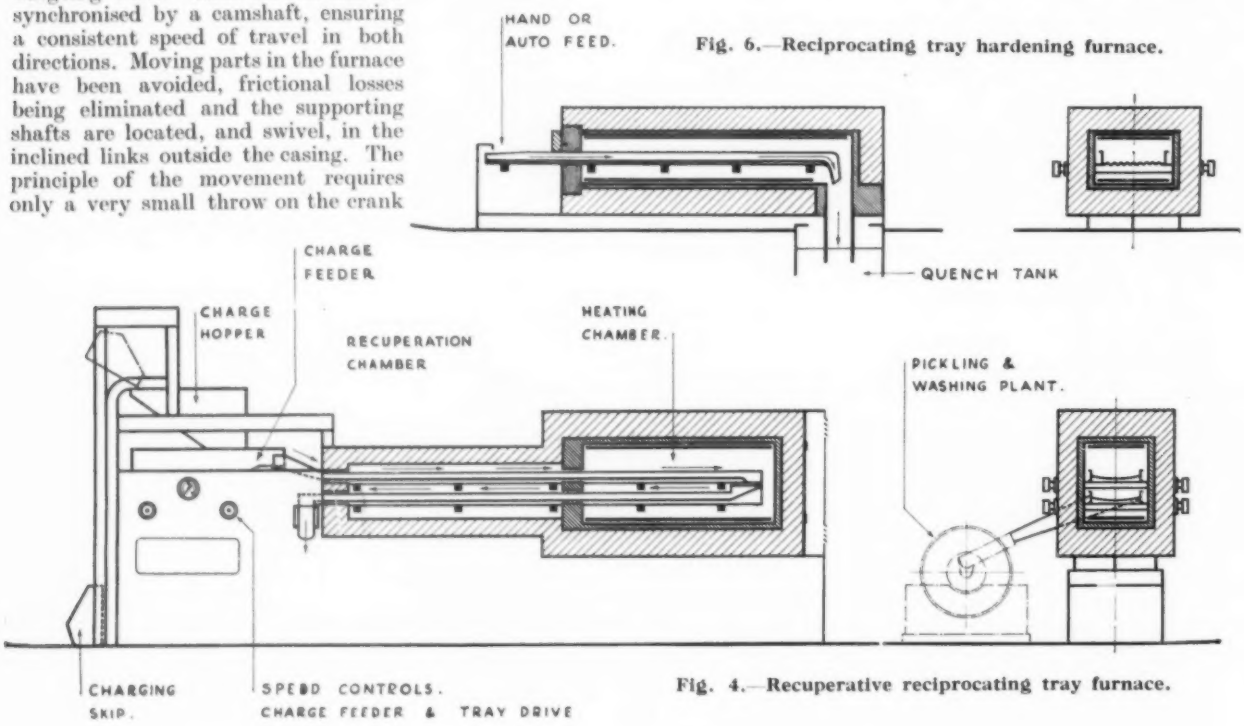


Fig. 4.—Recuperative reciprocating tray furnace.

within fine limits from a few pounps per hour upwards. From the discharge chute on the return tray the work emerges and feeds the rotary type pickling and washing plant of the usual design. The plant illustrated, RR. III has an average output of 1,100 lb. of brass pressings annealed per hour at 650° C.

The straight-through type of "Shaker" has many applications, the illustration showing a further type in course of construction for large diameter brass blanks with water-cooling spray. In comparison with existing pusher type furnaces, the "Shaker" furnace has a power consumption of at least 25% less without recuperation, and the initial cost compares favourably with gas or fuel-fired equipment. For this work automatic feeding is not essential, as the blanks, weighing 5–12 lb. each are handled by female operators. A further illustration is shown in Fig. 3, as applied to continuous hardening by the "Shaker" principle; to withstand the higher temperature, the tray is of a good quality nickel-chrome material, replacement of which is a comparatively simple operation.

From the foregoing it will be seen that the "Shaker" furnace has many advantages over other types, and these can be summarised as follows :—

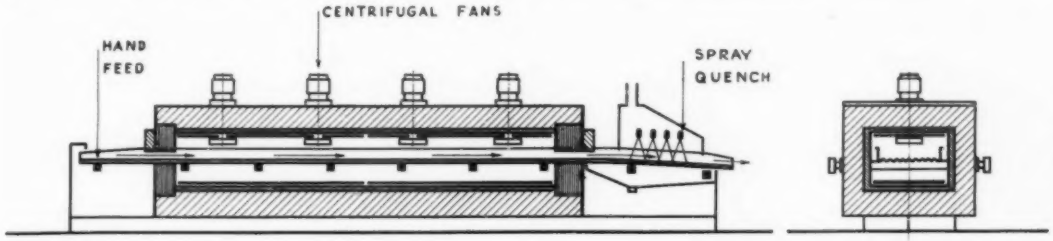


Fig. 5.—Reciprocating tray furnace.

(1) Total elimination of non-productive weight, with consequent saving in power consumption.
(2) Simplicity of construction and method of handling.
(3) Comparatively low initial cost.
(4) Unlimited field of application.

The drawings and photographs shown in this article are reproduced by courtesy of G.W.B. Electric Furnaces, Ltd.

Indium

THE name "indium" is derived from the fact that this metal's spectrum has indigo-blue lines. It is a relatively new discovery, being first spectroscopically discovered in 1863 by F. Reich and T. Richter. These two chemists were studying a couple of zinc blendes from Freiberg. After roasting had driven off from these ores the majority of their arsenic and sulphur, the residue was evaporated to dryness with HCl and distilled. This gave crude zinc chloride, which was spectroscopically studied in an endeavour to trace thallium, an element earlier discovered in kindred materials from the same mines To their surprise, however, the spectroscope showed a dark-blue line, very intense, and a less intense blue line, once the crude material had been purified. It was in this way that their attention was drawn to a new metallic element.

The metal itself is not found native, but is distributed over a considerable area, though in exceedingly small amounts. Many zinc blendes contain it in percentages ranging from 0·025 to 0·0142. It is also contained in smithsonite from Virginia and Tennessee, in copper from Oker, in calamine from Oriela (Bergamo, Italy), in zinc ore from Peelwood, New South Wales, in wolframite from Zinnwald, and in some iron ore and bauxites.

The metal itself has a silvery-white colour somewhat resembling that of platinum. It has a specific gravity in the fused condition of 7·128 and in the rolled condition of 7·277. The hammered metal has a specific gravity of 7·422. It is considerably softer than lead, extremely ductile, and is capable of rolling out into the thinnest foil. The Brinell hardness is given as 1·0, and the tensile strength with 0·29% of impurity is given as 7·99 tons per sq. in. The coefficient of thermal expansion is 0·0000459, and the melting point 155° C. Less volatile than zinc or cadmium, the metal does not volatilise when heated to the softening temperature of glass in a hydrogen stream. The boiling point is said to be 1,450° C.

Indium keeps its lustre in air and even under boiling water. It can be slowly dissolved by cold dilute mineral acids—e.g., sulphuric and hydrochloric acids. The atomic weight of the element has been variously estimated according to the method of obtaining it, but the best representative value appears to be 114·8, or, if a finer calculation is required, 114·864 plus or minus 0·0040. The atomic number is 49.

There are various methods of separating indium from its source. Indium-bearing zinc can be treated with adequate hydrochloric acid to dissolve the metal. When the spongy residue has stood for a few days, it is washed, dissolved in nitric acid, and the solution evaporated with a slight excess of sulphuric acid. The filtered solution is treated with ammonia, thereby precipitating indium and ferric hydroxides. The precipitate is then washed, and dissolved in hydrochloric acid. The consequent solution, which is virtually neutral, is boiled with excess sodium hydrosulphite. This gives off a fine crystalline powder as a precipitate, and this is purified by dissolution in sulphurous acid. The filtered solution is boiled, precipitating the basic sulphite free from iron. The basic sulphite is dissolved in sulphuric acid, and indium hydroxide precipitated by adding ammonia. This is converted into the metal by being heated in a current of hydrogen, or by fusion with sodium.

Cleveland Institution of Engineers

A joint meeting of the Cleveland Institution of Engineers and the Iron and Steel Institute was held at Middlesbrough, on December 15, 1941, at which Mr. L. F. Wright, President of the Cleveland Institution, presided. The meeting was arranged to discuss a paper entitled "The Practical Side of Blast-furnace Management, with Special Reference to South African Conditions," by Mr. R. R. F. Walton, which was originally presented at the 1940 Autumn Meeting of the Iron and Steel Institute, and is published in No. 2 volume of the Institute's journal for that year.

The paper gives a description of the two South African blast-furnace plants—the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of the associated company, African Metals Corporation, Ltd.,—with details of the furnace lines. Many features, associated with the raw materials used and with the coke employed, are unusual when compared with blast-furnace operations in this country. Considerable attention is given to the handling of the furnaces.

At the Middlesbrough meeting the paper was presented for discussion by Mr. J. E. Holgate, who emphasised the practical nature of the work described, paid tribute to the author for his valuable contribution to the existing fund of practical experience in the operation of blast-furnaces.

Conservation of Aluminium Used in Zinc Base Die-Casting Alloys

UNDER the sponsorship of the American Society for Testing Materials, a Committee on die-cast metals and alloys is carrying out a series of investigations with a view to the possible reduction in aluminium content of certain widely used zinc-base alloys. Before recommending any definite steps in the conservation of aluminium, the Committee considered that some positive tests should be made since questions were raised concerning possible manufacturing difficulties likely to be encountered relating to hot-shortness, shrinkage, solidification change and casting characteristics of lower aluminium alloys.

The two zinc alloys commonly used in the die-casting trade contain 4% aluminium and about 0·03% magnesium, in addition to these constituents the second alloy contains 1% copper. Both alloys are compounded with special high-grade (99·99%) zinc. The reduction in aluminium about which the investigations are concerned is from 4% to about 1·5 to 2·0%, and a statement of developments in this work has been prepared as follows :—

The eutectic in the zinc-aluminium system occurs at about 5% aluminium. Alloys containing 4% aluminium are therefore close to the eutectic constitution and have a short solidification range. As a result, they possess a minimum of casting difficulties, and the adoption of this aluminium content in the development of these alloys was based largely on the good casting properties coupled with what appeared to be the optimum combination of physical properties.

The alloys have been standardised in commercial use for over 10 years with satisfactory service records. Now, because of the aluminium shortage, investigations are in progress on the use of alloys with less than 4% aluminium. Preliminary results based on laboratory tests are now available and some conflicting commercial experience has been reported in the use of such low-aluminium alloys. This information, which is as yet incomplete, has been reviewed for the benefit of producers and users of zinc die-castings. There is, therefore, no assurance at present that properties on which tests are not yet available may not interfere with the use of these alloys in some instances, at least, just as difficulties with casting properties have already come to light as commercial trials have followed the laboratory tests.

With respect to laboratory tests, Apex Smelting Co. has reported a considerable amount of data from which is taken the following comparison of these two alloys :—

	Al %	Cu %	Mg %
I.S.T.M. Alloy XXV	4·1	1·0	0·03
Low aluminium substitute	1·5	1·0	0·03

	Alloy XXV.	Substitute.
Tensile strength, as cast, lb. per sq. in.	44,300	40,400
Tensile strength, 10-day, 95° C. water vapour	24,300	28,600
Elongation, as cast, %	5·3	5·7
Elongation, 10-day, 95° C. water vapour, %	3·7	5·7
Charpy impact (avg. gate and vent), as cast, ft.-lb.	38·5	34·0
Charpy impact (avg. gate and vent), 10-day, 95° C. water vapour, ft.-lb.	6·7	12·8
Dimensional change on 6-in. bar, 10-day, 95° C. water vapour, in.	−0·0002	−0·0006

The New Jersey Zinc Co. report that as far as their tests have gone, they have obtained substantially similar results, except in respect to dimensional change. Known slight differences in analysis and possible differences in casting practice will probably explain this discrepancy when complete data are available. The New Jersey Zinc Co.'s results indicate some difference between Alloy XXV and the 1·5% aluminium alloy, but the results are too incomplete to say whether the difference will be objectionable. They further report that to retain as favourable a comparison with the specification alloy, a low-aluminium substitute for the alloy containing 4% aluminium an 0·03% magnesium, must contain at least 2·0% aluminium.

Attention is drawn to the following points on which information is lacking or is incomplete. (1) The range of permissible die and metal temperatures has not been determined. (2) Some alloys of this type have been previously encountered which had a too narrow permissible range for commercial operation. (3) Creep resistance, which is a property of great importance in many uses of zinc die-castings, particularly where elevated temperatures are encountered, has not been determined.

Varying reports have been heard concerning the experiences of die-casters attempting to use these alloys. Some difficulties have been encountered, due to the difference in solidification shrinkage characteristics and greater hot shortness of the lower aluminium alloys. In some instances, these difficulties have been overcome by increasing the aluminium content from 1·5 to 2%. To what extent these difficulties can be overcome by attention to die design and casting practice is not yet known. In spite of the probability that a large number of castings can be successfully made with these alloys, the available evidence indicates that, due to the above difficulties, some castings cannot be produced successfully with alloys of reduced aluminium content.

Aluminium Technology

THE demand for accurate, up-to-date information on aluminium technology is greater to-day than ever before, mainly as a result of the war-time expansion of industries concerned with the working and treatment of aluminium alloys. Progress in various forms of construction associated with the war machine has been phenomenal, and aluminium alloys have played and are playing a very important part, but the need for information regarding these alloys has greatly increased, particularly in view of the fact that improvements in technique are continually being made.

In an effort to meet this need, METALLURGIA has devoted many editorial pages to practical aspects of the working of aluminium alloys, but the aluminium manufacturers have given much thought to this matter and are assisting considerably in meeting the demand Notable of these is the Research and Development Department of the Northern Aluminium Co., Ltd., which has compiled a number of publications dealing specially with various branches of the subject. These publications are subjected to periodic revision and their number is augmented in response to requests from many industrial sources.

Those available at the present time are included in following list :—

"Gravity Die Castings in Aluminium Alloys."
"Cold Forming of High Strength Aluminium Alloy Sheet."
"Machining of Aluminium Alloys."
"The Heat-Treatment of Aluminium and its Alloys."
"Protection of Aluminium Alloys during Storage."
"Specifications for Aluminium and Aluminium Alloy Products."

Copies may be obtained on application to the Technical Publications Department, Northern Aluminium Co., Ltd., Banbury, Oxfordshire.

Harper-Meehanite Castings

To obtain the maximum properties from iron castings consistently demands strict metallurgical control, careful selection of materials, laboratory control of melting and casting, and continual research investigation. But there is still a tendency to obtain the raw castings at the lowest possible cost without giving too much thought to the cost of the finished component, of which a casting forms the whole or part, or the actual service it will give. In modern iron foundries equipped and staffed to produce castings of the highest grade the extra cost of the castings is more than offset by reduction in machining time and the longer service that can be confidently assured. Such a foundry is that of John Harper (Meehanite), Ltd., Albion Works, Willenhall, and those interested in high-grade iron castings should obtain a copy of an interesting booklet on castings which they have recently published.

The Time Factor in Heat-Treatment Operations

By William Ashcroft

Considerable knowledge, skill and judgment are required for the proper performance of the many operations involved in heat-treatment; the rate of heating or cooling must be determined with reference to the physical or chemical requirements of the finished product and with reference to the mass, shape, and the manner of exposure of the material, all of which affect the rate at which it should be heated or cooled regardless of how fast heat could be transferred.

THE general trend in industry during the past year has been concerned mainly with increased production to meet the needs of the Forces, and in addition to great progress in stepping up production to a high level, the majority of individual operations have been substantially speeded up. In this general speeding up of operations, however, there is a tendency to overlook certain basic factors connected with some operations upon which great care must be exercised in order to ensure that the finished product will stand up to service conditions. One of these operations is the heat-treatment of components, the speeding up of which may result in the sacrifice of properties in the material which are of vital importance to successful service.

While the properties of all metals and alloys are affected by the manner and conditions under which they are heated to render possible many operations necessary in processing, attention is directed more particularly to those heat-treatment operations designed to modify the structure and constitution of the metal by controlling the heating and cooling conditions under which changes in the solid state occur. In most of these heat-treatment operations the primary object is the attainment of the final structure having the desired physical properties; but all the properties are not improved by any one particular heat-treatment process—as a rule a compromise must be effected to develop the most desirable properties in a material for a particular service.

The successful heat-treatment of a component is largely dependent upon the control of both heating and cooling of the component within relatively narrow limits, depending upon the alloy of which the part is composed, and the particular properties that are to be improved. Control is not only concerned with the use of modern appliances designed to assist in maintaining a uniform temperature in the heating chamber, but in controlling the time and rate of heating of the component in the furnace, and the atmosphere surrounding it when undergoing treatment. Fortunately, great progress has been made in the design of heat-treatment furnaces in recent years, and this has been of incalculable value in contributing to increased production; furnaces and equipment of a very high order are now in general use, but even with the best equipment available the great demand for materials possessing widely different properties calls for operators of considerable skill and experience.

With many components, particularly those for aircraft engines, there is a standard of accuracy of temperature and uniformity of heating, a degree of reliability and ease of control, that may not be attainable except with the most refined and elaborate methods. Many of these components are extremely light and fragile, and unless great care is taken in their treatment distortion results which may involve considerable machining of the component in the heat-treated condition. Not only is accurate equipment necessary, but the actual operation can rarely be speeded up without adding to the problems encountered.

In such cases heating must be carefully controlled, indeed most of the distortion encountered is due to the manner in which the component is heated, rather than to the quality of steel, improper quenching, or to machining strains. It is well known that steel expands on heating, and this expansion proceeds uniformly until the first critical point is reached (i.e., the Ac_1 line on the iron-carbon diagram). During further heating, up to the Ac_3 point, the steel contracts, and expands again as the temperature exceeds this latter critical point. Thus, if a steel component has considerable variation in sectional thickness and is heated too rapidly, the heavier sections may be still below the critical range and are expanding, while medium sections within the critical range are contracting, and very thin sections may be fully in solution and expanding. Obviously, if this simultaneous expansion and contraction is severe enough to load the material beyond its hot yield-point, a permanent set occurs and the component becomes distorted. On cooling, the component will be under stress and may rupture on quenching or shortly afterwards.

In such circumstances speeding up the operation must be avoided, since heating must be slow and uniform; the thicker sections should be permitted to soak, certainly during the transformation stage, in order that the difference in the temperature of thick and thin parts will be maintained as low as possible. If these precautions are taken very little distortion will occur during the heating of complicated components. But this problem is not entirely overcome by the exercise of care in heating, since distortion does occur with many components during quenching. This difficulty can be greatly reduced by quenching on a falling heat; particularly is this the case with high alloy steels. Material cooled in the furnace may drop several degrees before any structural change begins; with high alloy steels this lag is considerable, thus it is possible to raise the temperature of the steel until the desired structure is obtained, and to let it cool in the furnace to the lowest point at which the structure will be retained before quenching; in this way the effect of the quench is less drastic.

In the transformation of steel from the annealed pearlite condition through austenite to the final martensite of the hard state, a volumetric change occurs, which, according to Buchler, is in part dependent upon the quenching temperature. Most steels have a tendency to grow when quenched from a high temperature, and to shrink a little when quenched near the recalescence point. By recognising the importance of this variation and experimenting to find the most suitable quenching temperature, it is possible, with many components, to prevent volumetric changes almost entirely.

It should be remembered that sensitive hardening can only be performed successfully after repeated trial to find the most suitable quenching temperature and each heat of steel, even of the same nominal analysis, should be checked because the critical points will vary. There is much to be said for the preparation of a time-temperature diagram from a specimen of each heat of steel, upon which are located the Ac_1, Ac_3, and Ar_1 points, especially when the steel is to be used for complicated components that are to be hardened.

Sufficient has been written to indicate that to obtain the desired improvement in the mechanical properties of the steel by heat-treatment, the heating and cooling of the material are vital factors, but mention has also been made of the importance of the atmosphere surrounding the material undergoing treatment. For hardening, many

use a slightly carburising and very lightly reducing atmosphere and various methods are adopted to prevent or reduce scaling during the transference of work from the furnace to the oil-quench tank.

Case-hardening

The process of case-hardening is concerned with the production of a hard surface coupled with a tough core in the same material. Usually the material treated has a relatively low carbon content, and by heating it to a suitable temperature, in contact with carbonaceous matter or gas, additional carbon is absorbed at the surface and then diffuses into the steel. This causes the concentration of carbon in the steel at the surface to rise, whilst a little below the surface the concentration is that of the original steel. Provided the temperature of treatment is above the critical range for the steel used, the carbon will gradually penetrate inwards from the surface layer and a concentration gradient is set up.

Probably the greater amount of steel is case-hardened by the use of solid carburisers, which are materials rich in carbon and containing "energisers"; the steel parts to be carburised are packed in these materials and heated to the desired carburising temperature, which may lie between 900°–1,000° C. When a carburising gas is used the furnace charge may be heated to the carburising temperature in a neutral atmosphere, but when the right temperature is reached the atmosphere is changed so that the steel will be able to absorb the desired amount of carbon and produce the required concentration gradient inwards from the surface.

Whichever method is adopted, the furnace charge should be heated up gradually, certainly up to about 700° C., and beyond this to the carburising temperature the heating should be uniform. While the carburising temperature may be between, as already stated, the most generally adopted range lies between 875°–925° C. Case-hardening, however, is an operation that does not lend itself to speeding up, although the duration of a heat to give desired degree of carburisation to a charge can be determined from specimens taken from the charge. Checking in this way is not usual practice, but it offers possibilities of controlling the operation and reducing the duration of the heat to the time necessary for the desired degree of carburisation. In box carburising especially there is a tendency to extend the duration of this heat unnecessarily, and the checking of specimens from a charge would, in many cases, result in the speeding-up of this operation and the production of a desired case.

Speeding up this operation when delicate or complicated components are being carburised should be avoided; they should be heated very gradually to ensure uniformity, and it is important that such parts should not be quenched from the carburising temperature. If the charge is allowed to cool slowly and quenched at a temperature a few degrees above the Ar_3 point a high degree of refinement will be obtained. In such cases the quenching oil should be kept warm, since it is frequently better to sacrifice a little in the hardness of the case to obtain greater uniformity.

Tempering

Tempering is another operation in heat-treatment which should not be hurried. Its major purpose is to relieve strain caused by rapid cooling from the critical range. Hardness is produced very rapidly and is a function of the quenching temperature. Strain relief, on the other hand, is a function of time and temperature, and involves treatment for some hours according to the temperature used. Urgently needed components may be treated for five or six hours, and there is a tendency to regard much of this time as waste time, but the failure of a component in service, due to unsatisfactory treatment, can prove a very severe loss. Any speeding-up of this operation, therefore, should only be carried out after very careful investgation, since an unrelieved strain in one small part can easily cause an engine failure.

WANTED

Copies of Metallurgia for May and October, 1938.—G. E. STECHERT & CO., 2, Star Yard, London, W.C.2.

Conclusion

Generally, the operations involved in the heat-treatment of steel parts cannot be hurried without interfering with the properties desired. It should be borne in mind that many factors are involved, that the rate of heating or cooling the steel must be determined with reference to the physical or chemical requirements of the finished product, and with reference to the mass, shape, section, exposed surface, and manner of exposure of the steel, all of which affect the rate at which it should be heated and cooled, regardless of how fast heat could be transferred. Usually a low rate of heating permits of more thorough saturation, and this contributes to better quality of the heat-treated part.

May we take this opportunity of asking Readers to accept our Sincere Greetings and Best Wishes for the coming year.

Brazing Aluminium

THREE processes are stated by Miller to have the widest applicability in brazing aluminium—torch brazing, furnace brazing, and flux dip brazing. The first-named method generally involves a manual feeding of the metal into the joint, the necessary heat being supplied by torch. The second method requires assembly of the parts with preplacement of the brazing alloy and flux, and the use of a furnace to supply the heat. Either continuous or batch processes may be used. Flux dip brazing requires preplacement of filler material and the dipping of the assembly into a flux bath held at the proper temperature.

The development of processes for the brazing of aluminium and its alloys has been slowed up by the difficulty of removing the oxide film which interferes with the flow of brazing metal.

A number of aluminium brazing fluxes have recently been developed for producing brazed joints on a commercial scale. The primary functions of the flux are to provide a protective coating against further oxidation, to remove oxide from both base and filler metals, and to assist the free flow of the molten filler alloy.

In furnace and flux dip brazing only surface tension forces, sometimes aided by gravity, pressure or suction, determine the extent of flow and the final form taken by the alloy. In general, the alloy is placed near or in the joint, during or after assembly of the parts, in the form of wire, washers, strips, coatings, and so forth. When supplying the filler metal in all forms, except as a coating, the exact position and amount are usually determined by trial. In the case of a coating integrally bonded to the base metal, the filler material is already present on the formed parts, and it is necessary to design the assembly on this basis. The coating may be on one side or on both sides of the original sheet used in fabricating the parts to be brazed.

The author directs attention more especially to the flow of metal in the brazing operations, and concludes that aluminium brazing, though relatively new compared with non-aluminium brazing, appears to hold great promise, and should enjoy a bright future. Efficient fluxes, satisfactory brazing materials, and duplex brazing sheet are available. Sufficient information has been accumulated to define the properties of the joints, and improvements are being made daily. Once the mechanics of the flow of the brazing alloy are understood, the design of aluminium alloy joints for brazing should be a relatively simple matter.

Russian Open-Hearth Furnace Design

By D. W. Rudorff, A.M.I.E.E., M.Inst.F.

The war is making heavy demands upon Russia's basic industries, especially her steel industry, and since great development in steel manufacture has been made in that country in recent years, a brief description of an open-hearth furnace installation shows how experiences gained in Russia and abroad have been used in recent design to achieve the maximum efficiency in working.

AMONG the last reports on metallurgical developments in Russia published before the German invasion, the description of the installation of two 220-ton open-hearth furnaces at the Zaporozhe Steel Works is of special interest in view of the great efforts made by the Russian designers to make full use of latest experiences gained both abroad and in Russia.

The dimensions chosen for the furnace bottom, as outlined in the accompanying engravings, are the following :—

Length of bottom L	= 46 ft.
Width of bottom E	= 15 ft. 9 in.
Bottom area S	= 724·5 sq. ft.
Depth H	= 4 ft. 1 in.
Ratio L/E	= 2·92

Including one-third slag, the volume of the charge is found as V = 1,250 cub. ft., and the filling coefficient therefore is $k_b = V/(SH) = 0{\cdot}448$. In its centre, the bottom has a thickness of 41·4 in., this being made up as follows :—

	In.
Fused magnesite	9·1
Magnesite brick	20·7
Fire brick	7·1
Light-weight insulation	4·5
	41·4

The heat loss through the furnace bottom is estimated as 661 B.th.u. per sq. ft. per hour. The design of the furnace doors is entirely based on American practice. The door sills are water-cooled and of welded construction. As no detailed empirical data with regard to cooling water consumption were available, the amount of cooling water consumption to be expected was roughly estimated on the assumption that about one-third of the heat released in the furnace is carried away by the cooling water, while the heat loss through the working bottom alone amounts to about 20% of the heat input.

With regard to the service life to be expected of the roof, the designers point out that in Russian practice the longest service life observed at the Djerzhinsk steel works is 350 heats, while in other instances it was found to be as short as 30 heats. As the subjoined table shows, these figures are considerably inferior to the results obtained in other countries :—

	Heat in Tons.	No. of Heats.
Great Britain	85—138	485—300
United States	150—170	500—350
Germany	30—116	750—400

The shorter life of furnace roofs as experienced in Russian open-hearth practice, is of course largely explained by the lack of skill of the operating personnel and by the absence of expert supervision. In well-run furnaces, the wastage of the roof material should not be in excess of one-tenth of an inch per day. It is clear enough that with increasing free span of the roof, the thickness of the latter must be correspondingly increased. It appears that the Russian designers of the furnaces under review have based their layout mainly on the data published by J. Spotts McDowell* in choosing a thickness of 21½ in. at the skew backs and 18·1 in. in the free span. Owing to the type of doors employed, and in consideration of the great height of the roof, it was decided to adopt a rise of 1/5·5 of the span as compared to usual practice in which the rise is made 1/7 to 1/8 of the length of the span. This decision was made in full realisation of the fact that with such a great rise there exists the danger of opening up of the outer seams during heating up of the furnace. The original report also mentions that the height of roof employed in Russian practice is generally about 30% in excess of the height adopted in other countries.

* J. Spotts McDowell. "Sprung Arch Roofs of High Temperature Furnaces." *Heat Treating and Forging.* July, September, 1939.

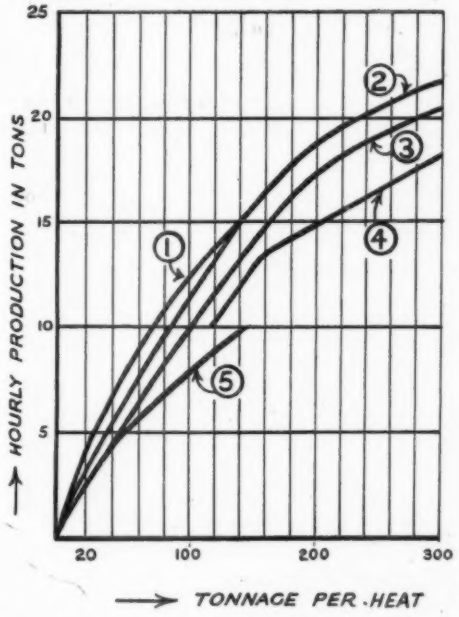


Fig. 1.—Tonnage per heat versus hourly production of open-hearth furnaces in various countries.

The relationship between the size of the heat and the hourly furnace output as obtained in British, American, Russian and German practice is graphically illustrated in Fig. 1. But these average data are actually exceeded in quite a number of plants. The annual production of the two 220-ton furnaces under review is estimated as 150,000 tons each. With outages assumed as 9·6% and with a heating time of 5%, the output per nominal hour is estimated to amount to 19 tons, or 20 tons per actual hour, with each heat lasting 10 hours 40 minutes.

The furnaces are heated with mixed gas of variable calorific value. With the products of combustion leaving the furnace at 1,700° C., the portion of the heat remaining in the furnace is estimated as 50%. With reversing every 20 mins., the resultant fuel loss is estimated as 8%, while with 10-min. periods it will be twice as large. The maximum heat requirements of the furnace are estimated as 119·1 million B.th.u. per hour.

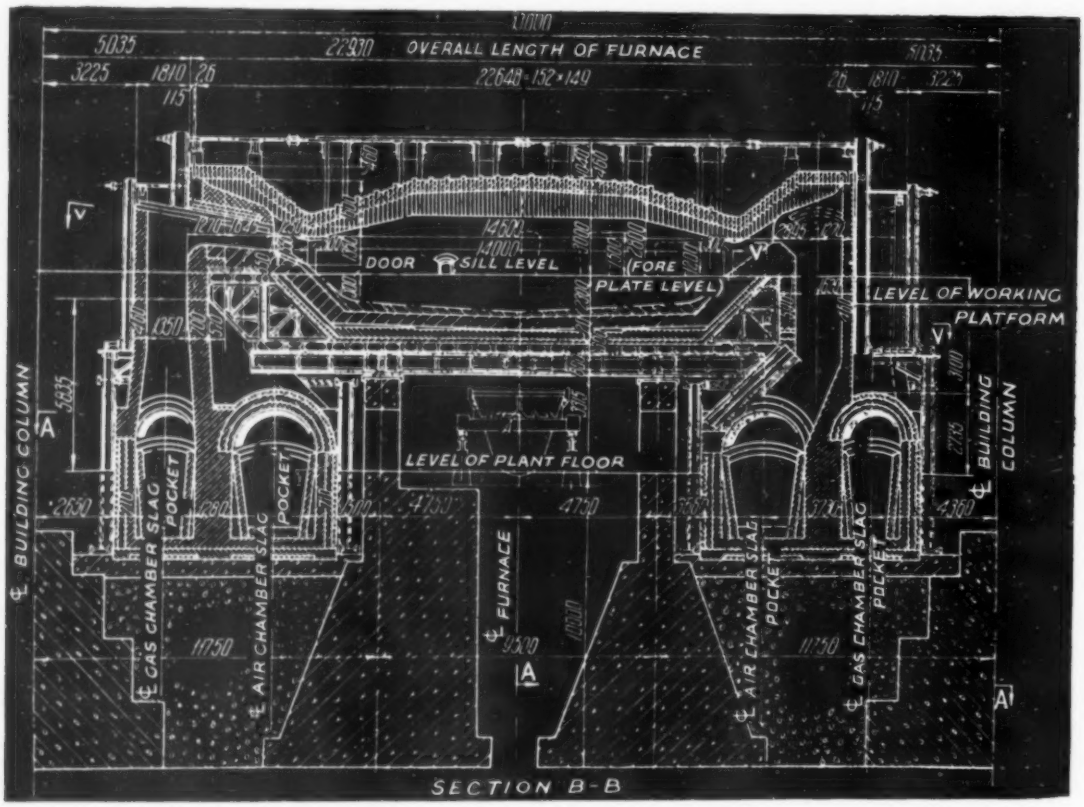
As the accompanying drawings show, Venturi type ports are employed, the design of which was based on the experiences made at Dzerzhinsk, Kuznetsk and Magnitogorsk, and also on data obtained from American practice.

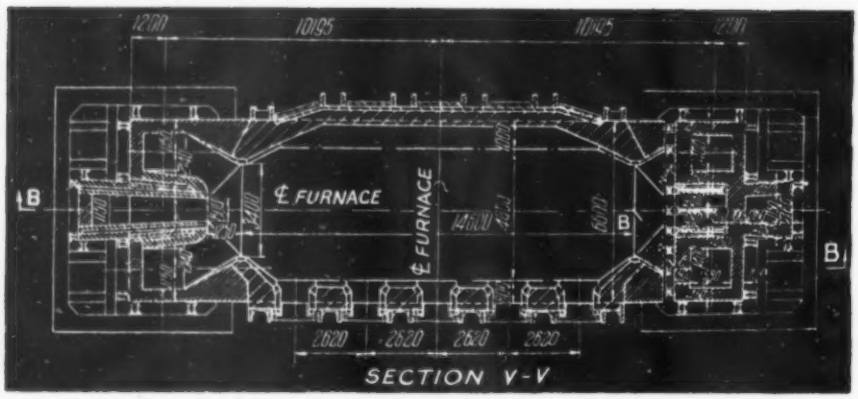
Some pertinent design data are enumerated in the subjoined table :—

DESIGN DATA OF VENTURI PORTS FOR 220-TON FURNACE.

	Flow Area, Sq. Ft.	Average Velocity of Flow at NTP, Ft./Sec.
Gas ports	3·96	gas : 24·6
Air ports	51·65	air : 3·94
Slope of gas port	top : 9°, bottom 5°	
Slope of air port	top : 35° 25'	
Elevation of bottom of gas port over level of door sill, 33½ in.		

As the illustrations show, the furnace bottom rests on nine flanged fabricated girders with webs 31½ in. high. The structural design of the furnace bottom is seen to be in close agreement with current American practice.





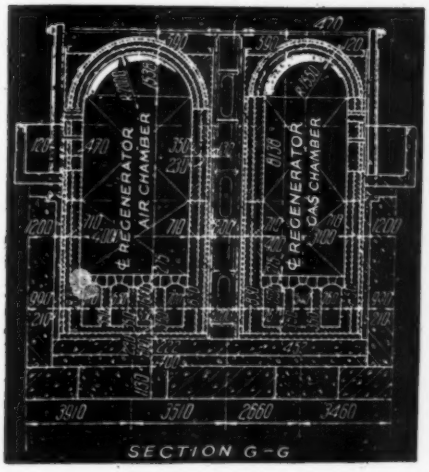
In connection with the design of the regenerators, the question arose as to whether the gas chambers should be built with a common or with separate partition walls. From practical experiences gained with installations fired with a mixture of coke and blast-furnace gas, or with clean producer gas, it was known that the common partition walls of the regenerator chambers require renewal after about 1–1½ years of furnace operation. It was also known that a partition space of 8 in.–16 in., or even 32 in., as employed in the Azovstal furnaces, between separate chamber walls does not always give satisfactory results. It therefore was considered that a minimum spacing of 4 ft. to 4 ft. 9 in. would be necessary. But it is emphasised by the Russian designers that the use of such a wide spacing involves a corresponding wide spacing of the slag pockets, and therefore implies the employment of curved gas canals. For these reasons, common partition walls are usually retained in American practice, while for the regenerator chambers either common or individual partition walls may be used.

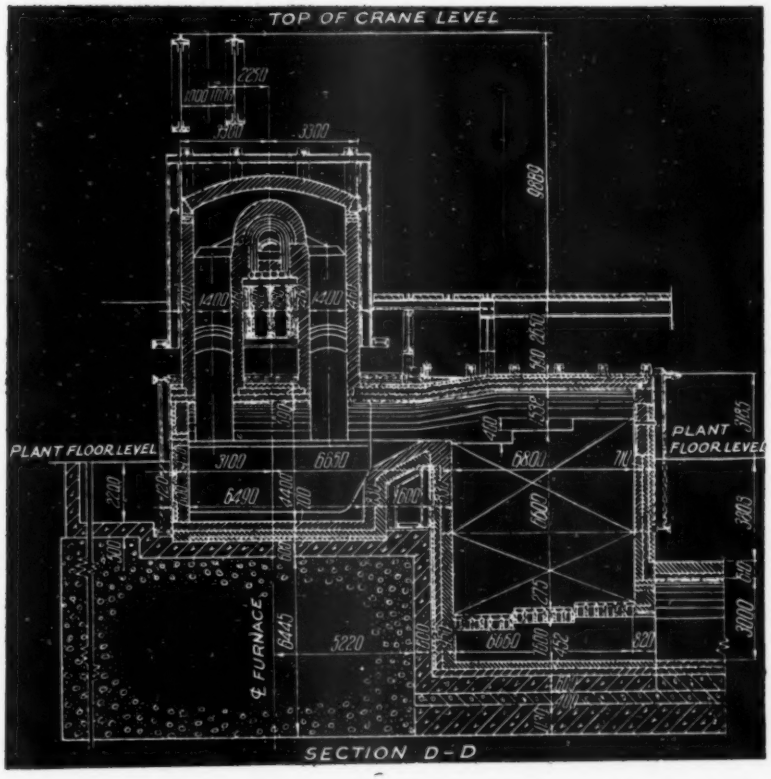
As the accompanying layouts indicate, it was decided to equip the slag pockets with joint walls and the regenerator chambers with individual walls. With regard to the relative merits of single-chamber and double-chamber regenerators, the table given below will be of interest. This table refers to a projected Russian open-hearth furnace of 185 tons capacity to be equipped with Blaw-Knox reversing valves.

COMPARATIVE DATA ON SINGLE AND DOUBLE-CHAMBER REGENERATORS FOR A PROJECTED RUSSIAN OPEN-HEARTH FURNACE OF 185 TONS CAPACITY.

	Single Chamber.		Double Chamber.	
	Air.	Gas.	Air.	Gas.
Final temperature, °C.	1,065	1,110	1,135	1,150
Flue gas temperature after checker work, °C.	570	545	510	490
Relative fuel consumption, %	100		92	
Flue gas distribution, %	67·8	32·2	65·4	34·6
Total draught requirements of furnace, in w.g.	2·64		3·46	
Relative material requirements, %—				
Structural	100		126	
Brickwork	100		130	

It is seen that the double-chamber design offers the advantage of higher gas-fuel and air temperatures, but it is also evident that the increased fuel economy is achieved at the expense of higher draught loss and higher capital cost. The service life of the checker work of double-chamber regenerators is estimated as 300–375 heats for the hot chamber and 600–750 heats for the cold chamber, and the designers came



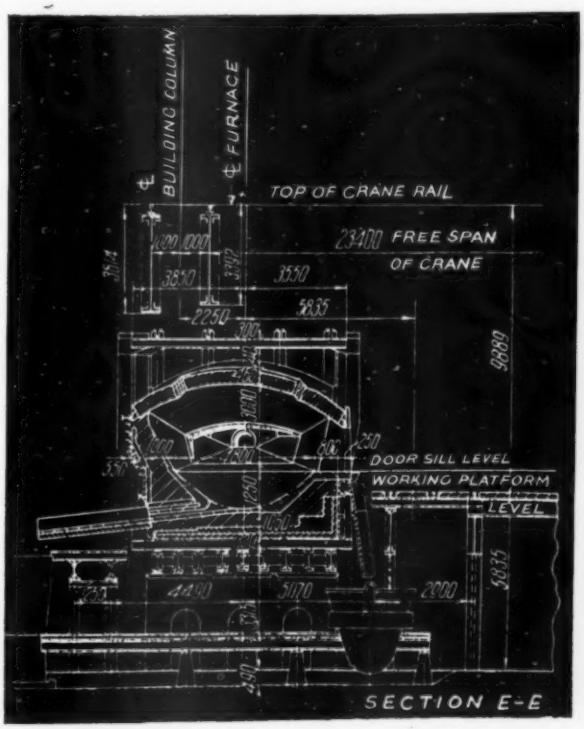


to the conclusion that on the average no greater service life is obtainable from the double-chamber design. The actual decision with regard to type and configuration of the regenerators was made with the use of the optimal shape coefficient as established by H. Trinius on the basis of his tests at the Ruhrort-Meiderich plant. This coefficient is given by the relation $H/\sqrt{F} = k$, where H is the total height of the chamber, and F is the area of the chamber, and k is the coefficient of optimal shape. For the regenerators of hot-working open-heath furnaces, the numerical values of the coefficient k should be 1·0–1·5, with heating both gas and air, and 0·75–1·15 with heating the air alone.

Generally it can be said that higher values of the coefficient k will be indicative of a short service life of the regenerators, while lower values will be reflected in a sluggish motion of the air and gas through the regenerator. In the layout considered here, the height of the regenerator chambers was conditioned by the depth of the foundations of the building structure and of the working platform. Accordingly, a value of $k = 1·27$ had to be chosen.

The layout of the slag pockets was based on the estimate that the quantity of collected slag will amount to about 12·1 lb. per ton of steel. This compares to a figure of 14· 3lb. per ton observed at Djerzhinsk, 1·22 lb. per ton at Zaporozhe, and 14·08 lb. per ton observed in American practice, these figures being based on producer gas as fuel. With the aforementioned figure of 12·1 lb. per ton, a total capacity of 6,920 cub. ft. for the four slag pockets was found to be required for 400 heats. The cubic contents of the individual slag pockets were based on a normal flue gas distribution ratio of 1·0 : 1·5 to the air and gas fuel regenerator chambers. It is expressly stated in the original report that in view of the sceptical attitude of Russian operators to liquid slag removal as practised in America, no provision was made for a later installation of this system.

Special consideration was given to the determination of the amount of checkerwork required and its arrangement. It was realised that the unit volume of checker work per unit surface of bath area, cannot be considered a satisfactory design criterion, as in actual installations the amount of checkerwork installed per square foot of bath surface is found to vary considerably. In American practice, variations from 14·85 cub. ft. to 18·9 cub. ft. per sq. ft. are encountered, while in German practice a range of 8·3 cub. ft. to 11·6 cub. ft. per sq. ft. is installed. The kind of fuel used is another determining factor. It was therefore considered preferable to follow the practice or basing the surface of the checkerwork required upon the amount of



heat released in the furnace. For furnaces fired with mixed gas, it is usual to provide 410 sq. ft. to 475 sq. ft. per million B.th.u. in German, 585 sq. ft. per million B.th.u. in American, and 435 sq. ft. to 570 sq. ft. per million B.th.u. in Russian practice. With a normal heat input of 79,400,000 B.th.u. per hour for the 200-ton furnace, the required checkerwork surface was therefore computed as 43,000 sq. ft. based on a specific surface requirement of 544 sq. ft. per million B.th.u. For the checkerwork, Siemen's bricks, giving openings of 6·3 in., were used. With this type of construction, 38·8 sq. ft. of heating surface are obtained per cub. ft. of checkerwork. The chief data of the regenerators are given in next column.

The air supply is taken care of by a Sirocco fan delivering 28,000 cub. ft. per min. at a static pressure of 4·4 in. w.g. The chimneys are 333 ft. in height, with a diameter of about

	Air Chamber.	Gas Chamber.
Cubic content of chamber in cub. ft.	9,637	7,448
Volume of checkerwork in cub. ft.	6,154	4,907
Total volume of checkerwork, cub. ft.	6,154 + 4,907 =	11,061
Heating surface in sq. ft.	24,532	18,990
Total heating surface in both chambers, sq. ft.	24,532 + 18,990 =	43,522
Free flow area, sq. ft.	135·6	105·4
Average flow velocity in ft./sec. at NPT with normal flue gas distribution	flue gas : 1·54	flue gas : 1·3
	air : 1·5	air : 0·94
Average final temperature, °C.	1,050	1,135
Temperature of flue gas leaving regenerator, °C.	570	495
Temperature of flue gas at end of flue, °C.	515	

9 ft., and give about 3 in. of draught. This draught is sufficient for handling the gases discharged with a heat release of 147,000,000 B.th.u./hour, 30% of the flue gases passing through the gas-heating chamber and 70% through the air-heating chamber. Therefore the available draught is considerably in excess of requirements, and thus permits a flue gas distribution of 38% through the gas chamber and 63% through the air chamber.

An X-Ray Investigation of Iron-Nickel-Chromium Alloys

THOUGH the ternary alloys of iron, nickel and chromium have been the subject of numerous investigations, primarily on account of their important magnetic, mechanical and corrosion-resisting properties, until recently no phase diagram had been drawn for all ranges of composition. Previous investigations have been for the most part concerned with the constitution at high temperatures, giving liquidus and solidus surfaces, with little reference to the transformations which occur in the solid state. The phase boundaries vary rapidly with temperature, especially in the iron corner of the diagram; this indicates that the alloys are very susceptible to heat-treatment.

The object of the investigation reported by Dr. A. J. Bradley and H. J. Goldschmidt* was to obtain a survey of the whole system at a lower temperature than previously, with the intention of constructing a rough map of the phase boundaries, which could be used as the basis of later investigations of the changes which take place in the solid state. Their work is therefore of a preliminary character, no attempt being made to attain high accuracy either in composition or in temperature control.

Shortly after the present work had been carried out there appeared a paper by Schafmeister and Ergang,[1] which gave a phase diagram for the whole system. They used microscopic, X-ray, magnetic and hardness tests to construct isotherms for 650° and 800° C. after heat-treatment for 1,000 hours. From the earlier work of Wever and Jellinghaus,[2] and Jenkins and his co-workers,[3] they were enabled to construct a space model showing changes of phase boundaries between 650° C. and the melting points. A tunnel runs in the space model between the σ phase field (FeCr) and the austenitic phase field (γ) on the Fe-Ni side of the diagram. Within this space ($\sigma + \gamma$) alloys are to be found. The tunnel walls are composed of the phase field ($\alpha + \gamma + \sigma$); Over the roof of the tunnel (above 920° C.) only the two-phase field ($\alpha + \gamma$) is to be found.

In the work by Bradley and Goldschmidt, X-ray powder photographs of iron-chromium-nickel alloys were taken in a 9 cm. camera using chromium radiation, the powders being slowly cooled down to room temperature. The positions of the phase boundaries on the constitutional diagram were estimated from the relative amounts of the different constituents present, the results used to construct the diagram reproduced in Fig. 1. Four single-phase fields were found, α, body-centred cubic (iron-rich), α', body-centred cubic (chromium-rich), γ, face-centred cubic (nickel-rich), and σ, complex structure (corresponding to the compound FeCr). The two-phase fields are $\alpha + \gamma$, $\alpha' + \gamma$, $\alpha + \sigma$, $\alpha' + \sigma$, $\gamma + \sigma$, and the three-phase triangles are $\alpha + \gamma + \sigma$ and $\alpha' + \gamma + \sigma$.

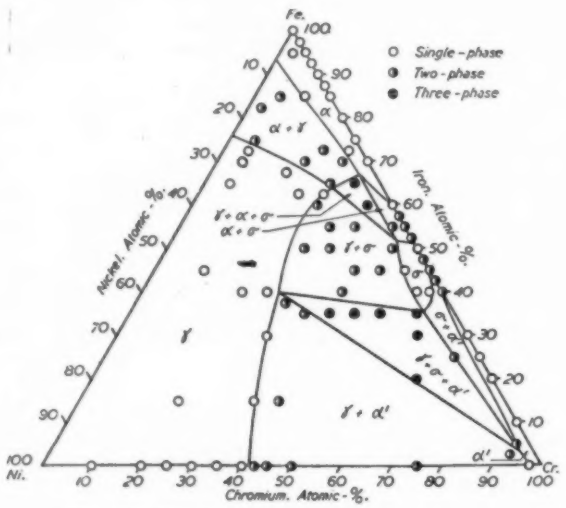


Fig. 1.—The iron-chromium-nickel system.

The results are in general agreement with Schafmeister and Ergang's results for 650° and 800° C., and therefore confirms the correctness of this model, but the phase boundaries are widely different in many places, showing that the system is very susceptible to heat-treatment, especially below 920° C., and will therefore repay further study, though very slow cooling and long times of annealing may be required. The work provides a further contribution to the study of the system and, in particular, shows that the X-ray method alone is perfectly capable of giving all the phase boundaries under the conditions used in the experiments cited. Schafmeister and Ergang considered that the presence of the σ phase in small quantities could not be detected by this means, but the present work does not confirm this conclusion, since the authors have detected the presence of the σ phase even further towards the Fe-Ni edge of the diagram than they report. In agreement with their results, the authors conclude that the ($\sigma + \gamma + \alpha'$) region can be successfully delineated by X-ray methods, whereas Schafmeister and Ergang stated it could not be detected by microscopic means.

* Bradley and Goldschmidt. Iron and Steel Institute, October, 1941. Advance copy.

[1] Schafmeister and Ergang. *Archiv. für das Eisenhuttenwesen.* 1939, vol. 12, p. 459.

[2] Wever and Jellinghaus. *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung.* 1931, vol. 13, pp. 93 and 143.

[3] Jenkins, Bucknall, Austin and Mellor. *Journal of the Iron and Steel Institute.* 1937, No. II, p. 187.

A Co-operative Investigation of the Factors Influencing the Durability of the Roofs of Basic Open-Hearth Furnaces

A review of a report is given, together with some of the general conclusions resulting from an investigation of the factors influencing the life of basic open-hearth furnace roofs. It is believed that the work done will help to establish certain of the factors which determine roof life and serve as a guide to the direction in which further work may profitably be undertaken.

THE results of observational work on the roof of a basic open-hearth steel furnace are reported by the Open-Hearth Refractories Joint Panel, working under the ægis of the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association, and were presented at the recent annual autumn meeting of the Iron and Steel Institute. The report consists of a foreword by Dr. T. Swinden and Mr. A. T. Green, chairman and secretary respectively of the Panel, and six sections, commencing with the raw materials from which the silica roof was made and ending with laboratory work on samples were taken from the roof at the close of the campaign. This investigation will undoubtedly help in establishing certain of the factors which determine roof life and will serve as a guide to the direction in which further work may most profitably be undertaken, and it will be of interest to review the report and present some of the general conclusions resulting from the work done.

Section I.—The Manufacture of the Roof Bricks and their Properties before Use

This section, by T. R. Lynam, Dr. J. H. Chesters, and T. W. Howie, deals with the materials and manufacture of the roof bricks used in the investigation. There is a present trend in favour of dense silica bricks for open-hearth roof construction, but the minimum porosity which can be attained is limited by the nature of the quartzite. The porosity of the quartzite used in the present work increased from 1% or less before firing to about 10% after firing; this feature of the raw material sets a lower limit to the porosity of the fired brick.

The principal materials used in the manufacture of the bricks were Bwlchgwyn quartzite 80%, and broken but unused silica brick 20%. The lime, sulphite lye and mineraliser were added in the form of a slurry, the lime addition being sufficient to raise the lime content of the fired brick to about 1.5%.

The quartzite and silica brick were passed through a jaw-crusher to a conveyer belt feeding the grinding mill. Samples taken from the conveyer belt showed that the quartzite varied in physical structure from the usual coarsely crystalline Welsh quartzite to a rather pebbly variety. Occasionally a pebble as large as 1 in. in diameter passed into the mill. Since it was thought that the various types might behave differently on firing, samples were taken for subsequent firing tests.

Particulars are given of the method of brick manufacture, including grading, moisture determination, moulding, drying and firing. Results of microscopical examination of thin sections cut through the samples before and after firing are summarised as follows :—

Normal Quartzite.

(*a*) Unfired.—Fairly uniform crystal size of about 0·3–0·5 mm. Some " voids " filled with much smaller crystals. Slightly wavy extinction.

(*b*) Fired.—Only about 30–40% of raw quartz left. Cristobalite formed at the edge of the grains and along cracks.

Pebbly Quartzite.

(*a*) Unfired.—Large strained crystals several millimeters in diameter cemented together with more finely crystalline quartz and some quartz of the size found in the normal sample.

(*b*) Fired.—Pebbly material seems loose in the matrix. Conversion appears to have gone further than with normal material.

Pebble.

(*a*) Unfired.—Very large crystals several millimeters in diameter (or a large number of small crystals of slightly differing orientation).

(*b*) *Fired.*—Conversion similar to that obtained with normal sample, but crystals divided into smaller units by bands of cristobalite.

The properties of the unfired and fired bricks are given, the latter including chemical analysis, refractoriness, refractoriness under load, porosity, bulk density, specific gravity, permeability, cold crushing strength, after-expansion, reversible expansion, spalling resistance, and microstructure.

It has been found that comparatively large quartz pebbles may be converted more rapidly than fine-grained rock of the normal type; X-ray studies have shown that this is a result of strain in the crystal lattice. X-ray investigations also suggest that, while there may be no obvious relation between the fineness of grinding and the rate of conversion, the more finely ground fraction yields a greater proportion of tridymite in the conversion product.

Section II.—The Furnace and Pyrometer Installation

The furnace selected for the work was an 80-ton fixed basic open-hearth furnace of normal construction. The roof arch was built with a rise of 1¼ in. per foot space; the steel skewback channels at the back and front of the furnace were at the same level. The roof was not level from end to end, but had a rise of 17 in. from the ends to the middle; the height of the middle of the crown above sill level was 6 ft. 9½ in., while at the ends of the furnace the height was 5 ft. 4½ in. The shape of the brick used was an end arch 12 in. × 6 in. × 3–2⅞ in., and the whole roof was built-bonded, using 12 in. × 9 in. × 3 ·2⅞ in. end arch alternately at the straight joint at each end. The roof was set dry except where it was necessary to correct the alignment for bonding the courses. No allowance was made for expansion across the arch, but longitudinal expansion was met by placing felts (12 in. × 3 in. × ⅛ in.) in alternate cross-joints.

A bad feature of the bonded roof was very clearly illustrated—viz., the slipping-through of odd bricks as a result of local unevenness. This is very difficult to avoid, even with new skewback channels, and bricks of good shape and size; with straight rings this fault does not arise. However, the sharing of the load in a bonded roof is advantageous during the later stages in the campaign, when parts of the roof have worn thin.

The temperature of the internal surface of the roof was determined by a water-jacketed lens-type receiving tube, working in conjunction with a recorder based on the

potentiometric principle and incorporating a galvanometer of high sensitivity. A steel platform attached to the structure at the back of the furnace was built to carry the complete radiation unit, while a special chrome-magnesite refractory block, with a conical sighting hole, ensured correct alignment on the target, which was an area roughly 5 ft. in diameter situated in the centre of the crown longitudinally, but nearer the back wall than the front. It is essential that an air-jet be used in conjunction with the radiation pyrometer in order to keep the lens clean, and the instrument must be calibrated at regular intervals.

For the determination of the temperature gradient through the roof, ten special bricks were embodied in the furnace crown. Four of these bricks were located in the target area covered by the radiation unit. Each had a hole drilled partially through from the outside, the holes being respectively 11½ in., 9 in., 6 in., and 3 in. deep. The roof was 12 in. thick, thus thermocouples inserted in the holes would give temperatures ½ in., 3 in., 6 in., and 9 in. from the hot face of the crown. Two other bricks with holes 6 in. deep were placed 4 ft. from each end of the furnace on the centre line of the roof. Thermocouples, three platinum/platinum—13% rhodium, and three Hoskin's alloy (chromel-alumel) were inserted in these six holes and connected to a 6-point pyrometer for continuous recording. The temperature readings from the four remaining special bricks, placed near the front and back walls, were taken at intervals with a portable indicator.

Section III.—The Furnace Campaign

This section is divided into four parts, the first concerns the conditions of service with particular reference to the temperature gradient through the roof; this is reported by A. E. Dodd. Part 2 deals with the nature of the dust in the atmosphere in a basic open-hearth furnace, and is presented by Dr. J. H. Chesters and W. Hugill. J. E. Doyle and W. J. Collins report on the draught conditions during the campaign in Part 3; while in Part 4 J. E. Pluck gives details of repairs to the roof during the campaign.

Considerable attention is given to the warming up of the furnace in Part 1. Gas flares were used, with individual control. During this warming-up period the temperature was recorded at the hot face, and at position indicated in the previous section. This temperature record is given in a graph from which it is seen that the temperature of the hot face increased steadily to 300° C. over a period of 48 hours; the rate of heating was then somewhat accelerated and the exposed surface of the roof attained a temperature of 600° C. after about 65 hours. At this time the temperature gradient through the centre of the roof was as follows:—

Position	Hot Face.	½ in. Back.	3 in. Back.	6 in. Back.	9 in. Back.
Temperature	600° C.	580° C.	510° C.	400° C.	260° C.

Spot readings taken at different points on the roof, all 6 in. from the hot face, at this time (before gassing) gave the following results:—

	East End.	Centre.	West End.
Charging side	300° C.	—	321° C.
Middle	—	400° C.	530° C.
Tapping side	285° C.	—	330° C.

During the preliminary warming up the valve was set on centre, following the usual practice, and these temperature readings illustrate the cooling effect of the draught from the doors to the ports; the middle of the roof bricks at the centre of the furnace was roughly 100° C. hotter than the middle of the bricks at the ends of the roof.

Until a few minutes before the furnace was gassed, the stack damper had remained down. The effect of raising this damper just before gassing was remarkable: the temperature of the face of the roof fell from 600° C. to 350° C. within about 10 mins. From the accompanying temperature changes within the body of the brickwork it is clear that the pull of the stack after the damper was raised was sufficient to draw air through the roof. The inference follows from the following figures:—

Distance from hot face in inches	0	½	3	6	9
Temp. drop on raising stack damper in ° C.	250	80	10	10	10

On gassing, the temperature of the inner surface of the roof rose to 1,000° C. within a few minutes; the rate of heating then rapidly decreased, and the roof reached 1,400° C. some 12 hours after gassing. In spite of the chilling of the roof on raising the stack damper, the surface temperature had not fallen into the range in which spalling occurs as a result of the inversion of cristobalite; the temperature was considerably below the α–β quartz inversion point, however. This drop in the surface temperature would affect all quartz grains within about 1 in. of the hot face. A fall in temperature on opening the stack damper is difficult to avoid and has been observed at other plants; some modifications in procedure should be made to overcome this chilling. It may be noted that a considerable improvement has been achieved since this work was carried out, by building a fire at the base of the stack and subsequently opening the damper gradually and as late as possible.

During the warming-up period the rise of the roof due to expansion was measured, and it was found that the rise at the ends was notably less than at the centre. This may be attributed to two factors: (*a*) The temperature at the ends was lower than in the middle of the furnace, as already noted; and (*b*) since the roof was of the "whale-back" type, it lifted longitudinally as well as across the arch. The first effect was nullified after gassing, for the ends of the roof continued to rise while the centre remained practically stationary, but the longitudinal rise was still in evidence throughout the campaign. The temperature results indicate a sudden increase in the rise of roof about the middle when the temperature was passing from 200° to 300° C.; this serves to emphasise that the most careful attention must be paid to the rate of rise of temperature in this range, for the expansion consequent on the α–β cristobalite inversion causes very large movements in the brickwork and such movements have to take place against compressive forces of a high order.

The temperature distribution in the roof bricks during a week-end shut-down has certain features of interest. These are described for the second week-end of the campaign, during which the gas was shut off for 9 hours. On taking the gas out the temperature of the inner face of the roof falls so rapidly that, within a few minutes, it is cooler than the centre of the brick. When small repairs are in progress and the doors of the furnace are left open, the inner face of the roof continues to cool steadily. Immediately the doors are closed on completing the repair, however, the temperature of the inner roof begins to rise as a result of radiation from the bath and walls and conduction from the middle of the brick. Normally, the hot-face temperature never falls below 500° to 600° C. During a more lengthy shut down, the temperature of the inner face was 315° C. after five days; this was still above the critical spalling range for the cristobalite zone at the face of the brickwork, but on opening the stack damper prior to gassing, the temperature fell to 180° C. This observation emphasises the extreme importance of stack-damper adjustment when the furnace is off gas.

Spalling was not observed on any occasion. The most rapid heating up (after a repair to the bottom) involved gassing the furnace after only 6 hours preliminary warming. On this occasion a crack opened along the apex of the roof, owing to the sudden lifting of the arch; hence rapid heating may lead to a reduced roof life, even when no spalling is apparent.

Temperature Fluctuations during a Single Heat.—On tapping and recharging, the temperature of the inner surface of the roof falls 300°–400° C. very rapidly. This severe temperature drop affects the front ½ in. of the brickwork almost instantaneously, but 3 in. back there is a time lag of about ½ hour. Temperature fluctuations amounting to 200° C. also occur throughout the charging period; these follow the individual charging operations in a quantitative manner. It would appear probable that these severe temperature fluctuations, which must reduce the

rate of output in addition to introducing stresses in the furnace structure, could be somewhat levelled out by adjusting the sequence and spacing of the charging operation.

In addition to the violent changes in the roof temperature on tapping and charging, fluctuations of about 50° C. occur on each reversal. Since the thermocouple ½ in. from the working face also recorded a corresponding, though smaller, drop in temperature on reversing (20° C.), it is concluded that the inner surface of the roof does actually cool slightly during the few seconds while the gas is out of the furnace.

Progressive Change in the Temperature Gradient.—As the campaign progressed the temperature within the body of the roof increased at a fairly regular rate, owing to wear of the brickwork and, possibly, an increase in its thermal conductivity. Towards the end of the campaign the furnace became slightly out of balance, the roof temperature being 20°–30° C. hotter while the gas was entering from one end.

Seasoning.—The change in temperature gradient just noted was most marked during the first two weeks of the campaign ; the most significant feature of this change was the increased conductivity of the cristobalite zone at the hot end of the brick. This suggests that one important effect of seasoning is the elimination of the sudden drop in temperature at the hot face of a new roof. The temperature gradient alters its course at the junction of the cristobalite and tridymite zones, so that the crystallisation of cristobalite at the hot face of a roof may be considered to be an essential feature of seasoning.

Other important features of seasoning appear to be a marked decrease in porosity and an increase in refractoriness.

Temperature Variation in the Roof at Different Positions in the Furnace.—During the first two months the centre of the roof was hotter than either the tapping or the charging side. During the third month there was a sudden increase in temperature at the tapping side ; this was associated with a period of rapid wear along the back of the roof and is attributed to wear of the parts followed by poor flame control.

The Nature of the Dust in the Furnace Atmosphere.—A number of attempts were made during the campaign to obtain information on the nature of the dust in the furnace atmosphere. The methods adopted were (*a*) filtering the furnace gases aspirated from the downtakes over a period of days, and (*b*) the deposition of dust on a platinum-lined refractory spoon. Dust samples taken from the flues and checkers were also examined.

Under the operating conditions at this plant, the amount of dust contained in the furnace atmosphere was about five times as great during the charging period as during melting and refining. The dust during charging consisted largely of lime, but during melting iron oxide preponderated. The actual weight of iron oxide deposited per unit time was approximately constant, which may be taken as additional evidence that this oxide is present in the furnace atmosphere as vapour. When using mixed scrap, as in the present case, considerable amounts of non-ferrous metals may be introduced into the charge. Of these, lead and zinc are perhaps the most important ; the zinc oxide is the less volatile and condenses in the checkers, while the lead oxide concentrates in the flues. It has been shown elsewhere that zinc oxide may cause serious slagging in the regenerator chambers, but none of the non-ferrous metals appears to be responsible for the wear of refractories above the stage level ; the last statement excludes the collection of metallic lead sometimes encountered below the hearth.

Section IV.—Examination of Samples Taken from the Roof at the End of the Campaign

After a life of 19½ weeks the furnace was taken off for general repair. A day or so after the gas had been taken out the roof was carefully examined and bricks from certain areas were marked as samples for laboratory work. The examination of these samples is reported by Dr. J. H. Chesters, B. W. Methley, T. R. Lynam, T. W. Howie, and A. E. Dodd. The method of sectioning the sample bricks closely follows that adopted by previous investigators. In the microscopical work, which is reported in Section VI by W. Hugill, other less obvious zones have been located and examined.

Section V.—The Results of X-ray Studies of the Raw Material and of Used Silica Brick from the Open-hearth Furnace Roof

This examination, by Dr. A. H. Jay, was conducted in two parts, the first dealing with raw materials and structural changes after firing, and the second with used silica bricks taken from the roof. The former examination, which was carried out by the back-reflection X-ray method, was made to determine the crystalline texture of the raw material and the degree of conversion of the quartz after firing with respect to the size of the crushed particles. The second examination was carried out to determine (*a*) the constitution of, and (*b*) the crystalline development in six chosen zones of a used silica roof brick. The powders were taken out of those used for chemical analysis.

The Absorption of Fluxes by the Roof.—The zoned appearance of the used roof bricks followed normal lines, but certain important new features were noted during the laboratory work. The iron-oxide content of the cristobalite zone was somewhat higher than that of the tridymite zone, contrary to the findings of many previous investigators. The lime was found to have concentrated a little nearer to the hot face than the pale yellow zone usually assigned to it. The refractoriness of this calcareous zone was 1,685° C. for a cut specimen and 1,640° C. for a powdered specimen ; the permeability of this zone was almost zero, owing to the presence of a continuous narrow band of glass. This glass, detected by microscopical and confirmed by X-ray studies, appears to be a eutectic of mellorite (a complex lime/ferric-oxide silicate) and excess silica ; this eutectic melts at a low temperature (about 1,160° C.) and is therefore a factor of considerable importance in the life of the roof. Furthermore, in several samples a crack coincident with this band of glass was observed running through the brick.

Furnace gases can pass through the brick, and analysis has shown a concentration of sulphur compounds at the cooler end of the roof bricks ; interaction between the sulphurous gases and the iron oxide present in the brick may give rise to several pink, red or purple zones.

The Effect of "Foaming."—During a period of close observation when a charge was foaming badly, it was found that the surface temperature of the roof reached 1,760° C. for a few minutes ; the bricks dripped during this short period of intense heat. The temperature record and observations during this stage confirm the widely held view that considerable damage may be caused to the refractories by the intense heat associated with foaming.

New Alumina Insulating Cement

The Thermal Syndicate, Ltd., have developed a new alumina cement for insulating and securing electric heating elements of nickel-chromium alloy wound on Vitreosil furnace linings. This cement has been submitted to severe tests and is now used regularly in the company's own laboratory, as well as by other firms, with entirely satisfactory results.

Since insulating cement for this purpose has usually been imported, it is noteworthy that a home-produced material is now available which can be used with safety and at the same time does not injure either the element or the Vitreosil. Further information regarding this material is available from the Thermal Syndicate, Ltd., Wallsend, Northumberland.

Some Notes on S 77 Steel

By Bernard Thomas, F.Inst.P., F.Inst.F.

As a general rule, it is not advisable to depart from quenching instructions laid down by a particular specification, but in exceptional instances modifications to normal practice may be useful in obtaining the properties desired. Such a case is given.

FACT was ever stranger than fiction, so the scribes inform us, and occasionally this is borne out in the less romantic circles of industry. In these notes mention is made of obtaining improved physical results from S 77 steel by departing widely from the theoretical quenching temperatures as laid down both by theory and specification.

S 77 steel resembles closely the BSS 5005/202 Specification with the exception that the manganese is given as 1·20% maximum instead of 0·40–0·80%, together with the slightly lower limits of sulphur, and phosphorus as befits an aircraft forgings specification. The full figures are shown in Table I.

TABLE I.
SPECIFICATION OF S 77 STEEL.

Carbon	between	0·25 and 0·35%	
Silicon	not more than	0·30%	
Manganese	"	"	1·20%
Sulphur	"	"	0·050%
Phosphorus	"	"	0·050%

S 77 is nominally, of course, a " 30 carbon " hardening quality in the " S " series.

The physical properties demanded are not high, the actual limits being shown in Table II for reference.

According to the iron-carbon diagram the nominal Ac3 point for a 0·30% carbon steel would appear to be in the region of 830°–840° C. Manganese would tend to lower this point, but the reduction is cancelled out by the time lag in transferring components to the quenchant, and in consequence, presumably, of this, the quenching temperature is laid down as 870° C.

TABLE II.
PHYSICAL PROPERTIES SPECIFICATION FOR S77 STEEL.

Maximum Stress	between 30 and 40 tons per sq. in.		
Elongation	not less than	25%	
Reduction of Area	"	"	50%
Izod Value	"	"	25 ft.-lb.
Brinell	between	131–174	

In the use of steels of " S " series, one usually endeavours to conform to specified details, and despite the low limits demanded by the specification, trouble was experienced in a certain direction by the poor figures yielded on the Izod impact values. Sometimes the returns would show impacts between 15 ft.-lb. and 20 ft.-lb., and, as reference to Table IIIA will show, even the average was relatively poor, although above the minimum demanded. The figures given in the table are averages of five tests, in each case the specification minimum being included for purpose of comparison.

TABLE III.
PHYSICAL TESTS—AVERAGE FIGURES YIELDED.

	A	Specification Minima.	B
Ult. Stress, tons/sq. in.	38·5	30–40	35·08
Elongation, %	32·4	25	35·5
Reduction of Area, %	67·2	50	66·5
Izod Impact Value, ft.-lb.	31	25	88
Brinell	170	131–174	149

Treatment Given

Test-pieces "A" were quenched from 870° C. in oil after 1 hour soak, and tempered 650° C. for 1 hour, and quenched in water.

Test-pieces " B " were quenched from 780° C. in oil after 1 hour soak and tempered 720° C. for 1 hour and air-cooled.

Soaking time at 1 hour should have been ample, as the test-pieces were merely ½ in. diameter, so that with this point ruled out attention was next turned to experiments with tempering. As the normal limit of 650° C. was already being used, further increases merely resulted in a fall in ultimate stress value and Brinell hardness without improving the impacts. Fractured specimens looked coarse despite normalising prior to heat-treatment, and, because of this, experiments were next made with dropping the quenching temperatures. At once an improvement was noticed in the desired direction, and accordingly the efforts were continued until finally standardisation was established at quenching from 780° C. instead of 870° C., oil still being employed as the quenchant. Table IIIB will show that the impact average has now improved by over 300%, and the actual fracture of the test-pieces was also better than those from the higher temperature, as would be expected from the figures in the table.

A curious feature is that the higher tempering temperature is possible after the lower quenching point, and while occasionally this was successful from the 870° C. efforts, the results were, in the main, too inconsistent to be of value. Admittedly, doubts may be expressed by some regarding the transitional stage approaching too nearly that of the pearlite condition, but the higher impact values thus obtained are certainly more desirable than those which operated for treatments nearer to schedule.

Theoretically, the above is all wrong, but in the face of actual fact from the figures obtained little criticism can surely be offered. It should be added in conclusion that the tests were made on material from the same cast of steel, and the analysis was naturally checked on actual test-pieces which had given low returns, the Release Note figures not being taken at face value.

Where deviations from specification of the foregoing character are made, it should be remembered to endorse same on Release Notes covering components involved, in order to comply with the conditions laid down.

The Electrolytic Deposition of Copper

As a result of a study by Newton and Furman,* an explanation has been found for the apparent paradox that the higher the concentration of copper in an ammoniacal solution and the more effectively the solution is stirred, the less chance there is of depositing copper at the cathode. The explanation is given in the following terms :—(1) In an ammoniacal copper solution there is a very small polarisation of the reduction of cupric to cuprous copper. At moderate applied potentials the deposition potential of copper is not attained until the copper has been largely reduced to the cuprous state. (2) With metallic copper at equilibrium, in ammoniacal solution the ratio of cuprous to cupric concentration is of the order of 100 : 1,000 : 1, in spite of the smaller dissociation of the cupric ammonia complex. (3) The inhibition of copper deposition from ammoniacal solutions is increased by increasing the copper concentration. A more rapid absorption of oxygen, chiefly by reoxidation of cuprous copper, prevents the solution from reaching the equilibrium that will permit deposition of copper. (4) Stirring the electrolyte aids the reoxidation of cuprous copper at the anode and also accelerates the absorption of air oxygen. Hence, in contrast with most electrodeposition processes, stirring tends to interfere with the deposition of the metal.

*"Studies on the Electrolytic Deposition of Copper." The Electrochemical Society, October, 1941, General Meeting.

The Heat-Treatment of Tool Steels

By A. J. Schroeder, D.Sc., D.Sc.(Eng.)

The quality of tool steels and their ability to function efficiently for their particular purpose in practice are dependent on the suitable correlation of composition, hot working and heat-treatment. The latter operations are complex, and this general outline, which embraces all operations involved in the heating and cooling of tool steels will have a practical value.

THE carbon content in tool steels is determined within narrow limits, largely as a result of experience, for particular uses. With increasing carbon content, greater importance is associated with heating than with lower carbon steels, because of the greater sensitivity of increasing carbon content; the hardening temperature must be held within close limits; the cooling rate must be very close to the critical rate of cooling for maximum hardness; the tempering range is reduced, and the heating conditions, including the furnace atmosphere, mutt be correct, because little or no work is done on the tool after hardening. Owing to the stringent limitations associated with the heat-treatment of tool steels, this brief review of the subject, together with certain recommendations, will be helpful.

(I) Annealing

(A) Reason for Annealing.

(1) To remove coarse crystallisation, variations in structure and distortions, and to produce a uniform, fine grain with the most advantageous condition for machining and subsequent heat-treatment.

(2) To remove stresses.

Annealing is carried out (*a*) after rolling and forging (mostly in steel-works); (*b*) after cold-working by hammering, bending, drawing, etc.; (*c*) after cutting by means of turning, milling, planing, etc., the object being to prevent as far as possible distortion and cracking during hardening; (*d*) to soften or "anneal" previously hardened steel.

(B) Method.

(1) *Correct Annealing.*—For spheroidising, which reduces the crystalline state of a steel to a nodular cementite, the steel must be heated to a point slightly above its equilibrium temperature (approximately between 720° and 760° C.), whereas temperatures in the region of 700° C. are sufficient for stress relieving alone. Care should be taken that changes in the surface of the steel are prevented (i.e., carborisation, carbonisation, enrichment of sulphur). The steel should then be allowed to cool slowly.

Annealing temperatures (Table I): 680°–730° C. for carbon tool steels, 700°–800° C. for alloy-treated steels, 680°–800° C. for high-speed steels.

TABLE I.

ANNEALING AND TEMPERING COLOURS.

Annealing Colour.	Temp.	Tempering Colour.	Temp.
Dull red	650° C.	Pale yellow	200° C.
Blood red	700° C.	Straw yellow	220° C.
Cherry red	800° C.	Brown	240° C.
Light red	900° C.	Purple	260° C.
Salmon red	1,000° C.	Violet	280° C.
Orange	1,100° C.	Dark blue	290° C.
Lemon yellow	1,200° C.	Cornflower blue	300° C.
White	1,300° C.	Light blue	320° C.
		Blue grey	350° C.
		Grey	400° C.

(2) *Incorrect Annealing.*—(*a*) By exceeding the correct annealing temperature the steel becomes coarse-grained and loses in toughness. It is overheated steel.

If the steel is heated until it fuses, combustion products may penetrate and make it rotten. This is known as burnt steel.

Annealing of steel in a forge-fire is often unsatisfactory owing to the uneven distribution of temperature.

(*b*) By over-prolonging the process of annealing, the steel may become coarse-grained. This is over-annealed steel.

Overheated or over-annealed steel can be saved through hardening by subsequent annealing at the correct temperature for the correct length of time, or in the case of blanks by forging and annealing.

(*c*) Changes in the surface are often produced by either air, or products of combustion possibly containing oxygen, hydrogen and sulphur, coming into contact with the heated steel.

Carbonisation takes place when the steel comes into contact with oxygen with which the carbon in the steel combines, a scale being formed. Sulphur may possibly be absorbed from the combustion gases.

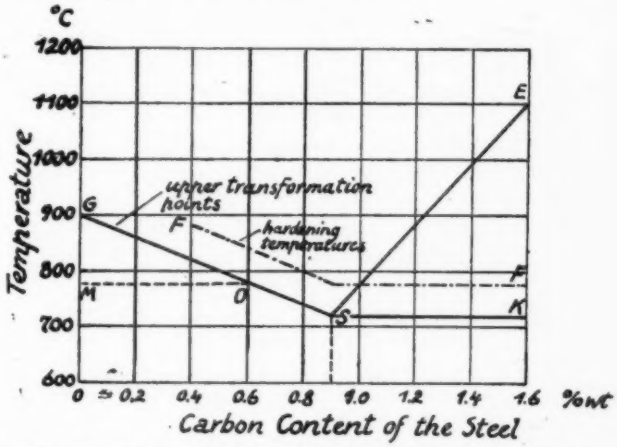


Fig. 1.—Optimum hardening temperature of carbon steels.

Surface changes of the steel can be kept to a minimum in gas or oil-fired furnaces by the use of a reducing atmosphere (i.e., excess carbon) and in the case of an electrically heated furnace by the use of an inert or protective gas. Finished tools can be reliably protected by packing in used carburising compound, spent charcoal, or cast-iron chippings.

(II) Hardening

Although hardening is an art and, even to-day, requires much practical knowledge, modern hardening installations considerably lessen the skill required and give most satisfactory results.

(A) Heating to Hardening Temperature.

Prevention of damage to the surface of the steel is effected in the same way as described for annealing.

The larger the piece of steel to be hardened, the more slowly should it be heated; where parts are of unequal section, it is advisable to preheat to a temperature of about 100° C. below the critical point, ascertaining that the larger sections are at the same temperature as the smaller. The final heating to critical temperature should take place more quickly. As a general rule, the higher the alloying additions in the tool steel, the lower its thermal conductivity, and this must be taken in to account in heating.

Hardening temperatures: Carbon tool steel, 750°–800° C. (Fig. 1); alloy tool steel, 750°–950° C.; high-speed tool steel, 1,150°–1,350° C.

The stipulations of the suppliers must be strictly observed.

The diagram (Fig. 2) shows the proportion of hardness to quenching temperature for steel with a carbon content of about 1%. The correct quenching temperature corresponds to the greatest hardness.

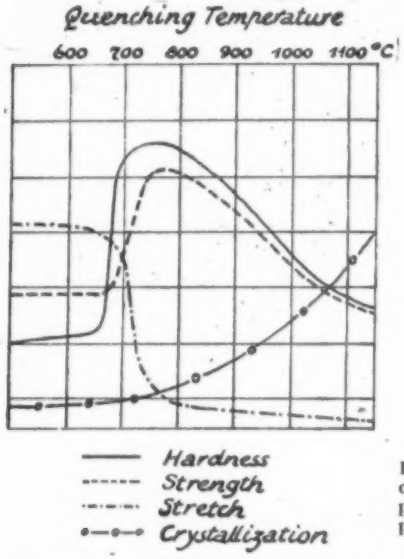


Fig. 2.—Influence of quenching temperature on the properties of steel.

Quite a reliable indication of the correct hardening temperature can be made with water-hardening steel, and also frequently with oil-hardening steel, by noting if the scale cracks off after cooling. If the scale adheres firmly to the surface of the steel a sufficiently high temperature has not been reached.

In the case of high-speed steel, the high temperatures required for correct hardening and the special alloying constituents make it necessary to include one or more preheating operations, according to the shape and size of the part to be hardened. These preheating operations take place from 200°–250° C., then 800°–850° C., and from thence to hardening temperature, or alternatively 200°–250° C., 600°–650° C., 900°–1,000° C., and from thence to hardening temperature.

The correct hardening temperature for the steel in question having been attained, it should be maintained for a short period varying from 0·5 to 5 mins., according to the size and structure of the tool. It is, of course, essential at this temperature to have a reducing atmosphere in the furnace chamber.

The transfer of the preheated steel from the preheating chamber to the hardening furnace should take place as quickly as possible, to eliminate, as far as may be, the formation of scale.

In the case of molybdenum alloyed high-speed steel, it is essential to cover the tool with borax powder after the preheating operation from 800°–850° C. This prevents the combination of the molybdenum content with oxygen of the air or furnace atmosphere, and avoids the formation of MoO , which leaves the surface of the steel as a yellow gas. This loss is detrimental to the properties of high-speed steel.

When parts of a tool are to be left soft, care must be taken that there is no abrupt dividing line between the heated and non-heated portions of the steel.

(B) Hardening of Tempering Furnaces.

The requirements of hardening and tempering furnaces are as follows :—

The chamber temperature must be as uniform as possible throughout. Regulation of the temperature must be simple, and at the same time it is essential that a predetermined temperature may be maintained within close limits for an indefinite period.

Heating must take place with as little influence on the steel as possible.

The furnace must be simple in operation, and work quietly and economically.

(1) The *forge* fulfills these requirements least, but because of its cheapness and convenience it is frequently used for the

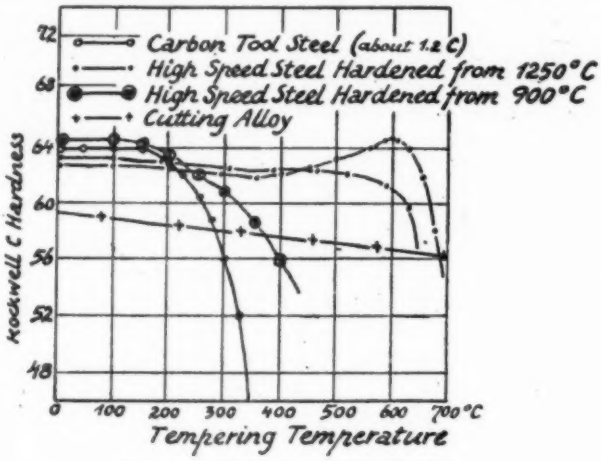


Fig. 3.—Resistance to tempering.

more simple types of tools. It should be composed of breeze or small coal and charcoal. Only when used with great care and skill is it serviceable with the more intricate tools. A small muffle of fire-brick built in the fire is useful, and enables the tool to be observed.

Measurement of temperature by means of instruments is not possible. Reliable approximate estimation according to the annealing colour is possible only under uniform illumination, with no direct sun or other lighting.

(2) *Gas Furnaces for Town Gas* (carburetted hydrogen) are very simple and clean, and adaptable for small and medium capacities. A reducing atmosphere to prevent scale and carbonisation can be easily produced by using excess gas. Muffles are more expensive and are only necessary when the workpiece must be protected from sulphurous gases. For high temperatures (high-speed steel) an air-blast is almost indispensable.

(3) *Oil Furnaces* are much used in place of gas furnaces, especially in cases where the capacity is greater.

(4) *Electrical Annealing Furnaces* are suitable for all temperatures. The heat is produced by elements or resistances composed of nickel chrome for temperatures up to as much as 1,000° C., carborundum for temperatures up to 1,300° C., or of molybdenum (with protection gas) up to 1,400° C. Electrical furnaces can be regulated automatically, very efficiently and simply.

The so-called critical point furnaces indicate the equilibrium temperature of a tool in the chamber, and, therefore, ascertain the correct hardening temperature automatically.

Electrical hardening furnaces are only economic provided they are in continuous use, and if the current does not exceed 0·05s. per kw.-hour.

(5) *Fluid Bath Furnaces* work very quickly and efficiently and also uniformly, and are, therefore, ideal for mass production. Heating of the bath can be by gas, oil or electricity. Metal (lead) is suitable for temperatures up to 900° C., salts (barium chloride $BaCl_2$, melting point 955° C., sodium chloride NaCl, melting point 802° C., potassium chloride KCl, melting point 750° C.) for temperatures up to about 1,400° C. Borax should be added to the barium chloride bath when used for hardening high-speed steel in order to avoid carbonisation. Salts become heated more slowly than metals, and prevent oxidation of the surface by the retention of a thin salt crust on the work when removed from the bath.

(6) Good *Tempering Furnaces* are essential for satisfactory heat-treatment. Simple plate or muffle-type furnaces may in this case be considered only a stop-gap, as the uniformity of temperature required cannot be guaranteed in such furnaces.

Tempering furnaces are used as follows: Oil-bath, gas, or electrically heated for temperatures from 100°–250° C., gas, oil or electrically heated salt or metal baths from 200°–600° C., electrical air circulation furnace for any temperature up to 700° C.

Automatic retention of the required temperatures is essential.

(C) QUENCHING.

This designation should strictly be used only in connection with cooling in water. The falling off of temperature in oil or air takes place so slowly that it should be termed cooling down.

The rate of cooling falls according to the following cooling agents:—

Mercury (rarely used except for needle points);
Water, with added acids or salts.
*Pure water.
Water and glycerine ($C_3H_8O_3$).
*Mineral oil (special hardening oil).
Rape oil.
*Air blast.
*Still air.

* Agents most frequently used.

Other agents date from the past, when heat-treatment was a mysterious black magic. Their actual advantages have never been proved.

Temperature of cooling agents: The effect of the cooling media depends on its specific heat; in other words, on its heat-absorbing capacity. Increased temperature of the cooling agents reduces the heat absorption from the work; a constant temperature must, therefore, be strictly maintained when water is used as a cooling medium. A water temperature of 20° C. which gives the best effects is usual. Higher temperatures promote the formation of steam bubbles, and increase the danger of scrap because of the different cooling rate that is connected therewith.

The effect of higher temperature is different in oil baths. Their fluidity is improved by the higher temperature, and the interchange of heat is, therefore, facilitated. Hence the cooling effect is not reduced.

In the case of an air-blast, it has to be taken into consideration that compressed air always carries small water drops, exposing the blown surface of air-hardening steel to a local water-cooling effect. This effect may lead to surface cracks. Air from a rotary blast is, therefore, to be preferred, although the blowing effect is not so strong. Cooling devices for partial hardening of engravings, borings, drillings, and working edges are used with all cooling media, and are fully described in specialised articles, as well as devices for straightening and hardening of thin discs between cooled metal plates.

Special subjects in cooling technique are *graduated* and *interrupted hardening*.

The definite change of martensite (i.e., the structure produced at hardening temperature) to austenite does not take place instantaneously, but during the cooling period between 300° and 180° C. according to the alloy. The tool should be cooled at a rate greater than the critical cooling speed to this point and then more slowly. The tool has then time to undergo the change in dimensions during the change of structure. Interrupted hardening is employed most advantageously for tools of intricate shapes and widely varying sections when made of water-hardening steel, and can be done by cooling rapidly in water to about 400° C. (disappearance of glow), and then slowly in oil. Quenching stresses are almost entirely eliminated in this way.

A similar method, *graduated hardening*, is effected by quenching in a heated bath (300°–180° C.). The tool is placed in the bath and cooled until the pre-determined bath temperature is reached, then in still air to room temperature.

(D) TEMPERING.

The structure produced by quenching undergoes a change through tempering, the extent of the change depending on the composition of the steel and the temperature employed.

(1) *Boiling, Stress-relieving and Ageing* take place at 100° to 200° C., the purpose being to strengthen the structure after harsh quenching of steels having a high critical cooling speed. Loss of hardness does not take place, nor is there an increase in toughness. This method is used for carbon steel and alloy-treated water and oil-hardening steel, in order to avoid subsequent alterations in dimensions of measuring tools, etc., through natural ageing, or to avoid scrap through subsequent bursting or cracking at changes in section.

(2) *Tempering, Toughening.*—The aciculate martensite is transformed into hardenite, or, at higher temperature, into troostite and sorbite, by this method. Not only are the stresses produced by quenching removed by such treatment, but also the toughness is greatly increased, though loss of hardness cannot be avoided in that process. The sphere of conspicuous decrease in hardness lies between 200° and 300° C. for all water and oil-hardening steel, except for high-speed steels and similar special alloy cutting tool steels with high-temperature characteristics. For that reason, the usual tempering temperatures also lie between the same limits and are chosen higher within these limits, the greater the pretensions made as to toughness and the less the requirements in regard to hardness.

(3) *Hardening with Subsequent Drawing* employs tempering temperatures from 350° to 550° C., by which the hardening structure is almost completely re-transformed into sorbite. There is, therefore, no longer the question of hardness in the sense of the steel treatment, but only of high strength. Tools used in hot or cold position and exposed to heavy effects of blow, thrust or pressure, or to rapidly alternating temperatures within the limits of the tempering temperatures are treated in the same manner as construction parts exposed to high stresses.

(4) *Tempering High-speed Steel.*—The fundamental structure of high-speed steel or related steel alloys consists of austenite after cooling, owing to the necessary high hardening temperatures. This structure is very brittle, but not too hard. It is therefore recommended to temper tools cooled from high hardening temperatures within temperatures that guarantee the decomposition of austenite into martensite. These temperatures lie between 550° and 600° C., according to percentage and type of alloy.

The hardness of high-speed steel increases through equilibrium in the structure of austenite-martensite, as shown by the curve in Fig. 3, which supposes an austenitic structure that has been cooled. If the hardening temperature was for some reason so low that the austenitic structure has not been created, the high tempering temperature cannot, of course, be employed. In that case high-speed steel is treated as alloy-treated tool steel, but even then it is questionable whether high-speed steel can be used at all.

(5) *Control of the Tempering Temperature.*—The tempering colour gives a clue to the degree of temperature attained for tools treated by air. For carbon steels and alloy-treated steels the tempering colour serves to fix correctly enough the tempering temperature within temperatures from 220° to 330° C., assuming that heating takes place uniformly and relatively quickly, and that the surface of the tool is completely free from a protecting layer of grease or salt. (cf. Table I).

Steels with high constituents of chromium, tungsten, or cobalt display no, or different, tempering colours, so that it is impossible to estimate the temperature. Measuring instruments must be used for such steels, as well as for the exact measurement of a temperature (Table II) to be retained longer than for 1 min. Tempering with its own

heat from the tool shank (chisel, riveting set, snap-head dies, etc.) is sufficient for small requirements, but for higher demands uniform heating of the tool body must be preferred even if it has been partially hardened.

(E) Cleaning.

For parts which are to be hardened brightly by a salt-bath cleaning is necessary, before heating, with the aid of boiling in soda-lye or washing in the usual cleaning agents.

Colour or crayon marks cause soft spots under certain circumstances, and must, therefore, be washed off.

Adherent remainders of metal or salt-baths must be scraped or brushed off.

Adherent scale is removed by sand-blast. For hardening with the aid of the salt-bath furnace salts, with a small admixture of cyan (CN) may replace sand-blasting for temperatures up to 900° C., if tempering is possible in an oil-bath a short time after cooling in water or bright hardening oil. High-speed tools which are pre-heated in, and hardened by, the salt-bath also remain bright grey, if they are cooled in a graduated fashion in an intermediate bath of 500° to 600° C., which is slightly cyanised. The salts residues of the intermediate bath are washed off in hot soda-lye, and then the tools are greased in hot oil. In this case sand-blasting may also be avoided.

(III) Main Reasons of Hardening Failures

(A) FAULTS IN THE INITIAL CONDITION.

No.	Type.	Group.	Fault.	Result.	Remedy.
(1)	Internal defect of material	(*a*)	Blisters Shrinkage Sponginess Forging or rolling faults.	Cracks caused by cooling from the hardening temperature mostly forming large chinks in the direction of grain.	Stringent delivery instructions. Select only trustworthy suppliers.
		(*b*)	Network of cementite Lines of carbide.	Serrated or netlike cracks caused during cooling from the hardening temperature.	As under (*a*) or when self-forged, adequate annealing treatment or re-forging.
		(*c*)	Material burnt by annealing.	Soft spottedness. Insufficient absorption of hardness. Abnormal strain cracks.	As under (*a*) or when self-annealed, re-annealing.
(2)	Machining strain.			Severe distortion. Abnormal strain cracks.	Anneal for stress relieving.
(3)	Faulty shape of tool.		Too great differences in volume.	Cracks along the voluminal confines. Bursting of edges and corners. Severe distortion.	Hollow the moulding corners. Round the edges. Bore out thick sections. When sharp corners are absolutely necessary insert round iron wire; in that case no conspicuous loss of hardness takes place on the corner edge. Apply supporting protection bars (Fig. 4) so that the corner edges remain soft. Use air hardening steels.

(IV) Measurement of Temperature in the Hardening Shop

The most important instruments for measuring hardening and annealing temperatures are included in the following survey (Table II).

All apparatus should indicate quite distinctly and accurately. Recording attachments are a great asset and are available except in the case of optical pyrometers, which are, therefore, to-day only in little use for permanent control, because they cannot be arranged for writing down their readings.

(1) *The Thermo-electric Pyrometers* really measure the difference of heat between soldered seam and connection. If the connection is sufficiently far away from the environs of the furnace heat and its variable temperatures, the source of this fault can be removed by compensating conductor wires. It has been found satisfactory to put the

TABLE II.
LIST OF TEMPERATURE MEASURING APPARATUS.

Principle of of Measurement.	Type and Description.	Arrangement.	For Temperatures up to.
Extension of liquid or solid bodies.	Mercury (Hg) glass thermometer in metal mounting.	Ordinary	300° C.
		with filling of nitrogen (N) (up to 20 atmospheric pressure).	550° C.
	Mercury metal tube thermometer.	Mercury under high pressure in solid or flexible metal tube.	600° C.
	Bar extension thermometer	Bar (or tube) of steel.	800° C.
		Bar (or tube of nickel steel or graphite.	1,100° C.
Thermo-electrical current.	Thermo-couples.	Copper-Konstantan.	400° C.
		Iron-Konstantan.	700° C.
		Chrome-Nickel-Konstantan	900° C.
		Nickel-Nickel Chromium	1,100° C.
		Platinum-Platinum Rhodium.	1,500° C.
Thermo-radiation.	Total radiation pyrometer.	With telescope.	2,000° C.
Annealing colours.	Partial radiation (optical) pyrometer.	With telescope.	1,800° C.

connections into the ground or to lead them into a thermos flask of commercial custom through plugs punched and caulked. The protection tubes easily fuse when they are used permanently at high temperatures, especially in salt-baths for high-speed steel. The protection tubes must,

(B) FAULTS DURING HARDENING.

No.	Fault.	Group.	Consequence.	Result.	Remedy.
(1)	During heating.	(*a*)	Incorrect hardening temperature (overheated or underheated).	Softness or large brittleness. Strain cracks. Insufficient working efficiency.	Supervise temperature.
		(*b*)	Too rapid heating. Core substantially remains below heating temperature.	Cracking of the hardened surface layer.	Keep heat a little under hardening temperature until it has fully penetrated into the tool, then raise to hardening temperature.
		(*c*)	Unequal heating in too small a furnace chamber. Wrong adjustment of the burner. Heating by forge fire.	Strain cracks along the limit of different temperature zones. Severe distortion.	Control the fire. Use a larger furnace chamber. Arrange better penetration of heat.
		(*d*)	Wrong furnace atmosphere produced by large surplus of air.	Carbonisation of the surface, resulting in soft surface layer or soft spottedness.	Correct the adjustment of the burner.
		(*e*)	Carburation of surface in consequence of packing in heavily carbonizing preservatives.	Breaking out of the working edges in use.	Use mild preservatives,
(2)	During	(*a*)	Too abrupt. Too soft. preservatives.	Strain cracks. No absorption of hardness.	Observe strictly hardening instruction.
(2)	During cooling.	(*a*)	Too abrupt. Too soft.	Strain cracks. No absorption of hardness.	Observe strictly hardening instruction.
		(*b*)	Adhering steam bubbles (Leidenfrost's drop).	Soft spottedness, under circumstances strain cracks.	Move tool in cooling agents. Arrange bubbling device in the cooling container.
		(*c*)	Wrong direction of dipping.	Severe distortion. Soft spots in engravings.	Dip in the direction of the longitudinal axis. Move in the direction of the longitudinal axis. Move engravings in the direction of the surface of the liquid
(*c*)	Scrap on the strength of processes arising from natural structure equilibrium	—	The necessary more or less abrupt cooling causes stresses or strains leading to distortion or cracks when tools have unsatisfactory shapes that cannot be avoided.		PRECAUTIONARY MEASURES (See *c*) Quenching) Treat water-hardening steels by means of the interrupted hardening. Harden oil-hardening steels by thermal bath.

therefore, be easily interchangeable. The measuring wires are easily corroded by hot gases and will then measure incorrectly. Their records must therefore be tested at regular intervals.

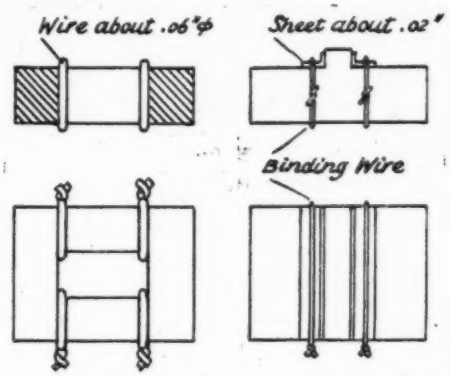


Fig. 4.—Protection of sharp corners during hardening.

(2) *The Radiation Pyrometers* direct the rays of the measuring place of the furnace towards the soldered seam of a thermo-couple, the thermo-power of which is measured or recorded as in the case of the thermo-electric pyrometer, or else the radiation heats a very thin resistance wire (bolometer), the resistance change of which is used for measuring—as in the resistance thermometer. Radiation pyrometers, like optical ones, cause little trouble, as they do not come in contact with the hot parts of the furnace. They are adjusted on black radiating bodies, and can, therefore, be used only where the self-radiation (without reflection of additional sources of radiation) of the body which is to be measured (furnace chamber, surface of a salt bath in the crucible at uniform temperature, or black bodies being annealed) influences the measurement. Considerable aberrations will arise in a semi-muffle or hearth furnace, the working chamber of which is passed by the fire gases. Furthermore, in instruments that concentrate the radiation by a mirror on the thermo-couple care must be taken that the reflecting power of the mirror is not impaired by dust, dirt or scratches. The apparatus has, therefore, to be readjusted frequently, and this is best done in the working position. These instruments are suitable for temperatures above 600° C. and are simple and convenient in use. The distance of their position from the furnace, the temperature of which is to be measured, is all the same in so far as the radiation is not diaphragmed by the opening of the furnace.

(3) *Critical Point Recorders* serve a more extensive purpose than pyrometers, whilst at the same time they record the critical point curve, dependent on the temperature of the steels that are to be hardened. By this means critical point recorders guarantee the correct hardening temperature even for any unknown steel, except the special alloy tool steels. They are connected directly with an electrical furnace in the shop.

The Welding of Copper and Copper Alloys by the Electric Arc Process

THE metallic arc welding of copper and its principal alloys, bronze and brass, offers many advantages, especially in the case of heavy sections, where the ease and economy of operation and the speed with which heavy deposits can be made are in its favour. Useful information on this subject is given in an 8-page brochure recently published by Murex Welding Processes, Ltd.

The easiest to weld are the bronzes; in contrast to these pure copper, both the electrical and ordinary grades, and the brasses are difficult arc-welding problems, if weld metal of identical composition is required. In this case welds are usually porous ; in copper, because of reactions between the molten metal and the gases present in the arc, and in brass because of the vaporisation of zinc, which is a metal with a low boiling point. Except for special conditions it is seldom that the weld metal need be of exactly the same composition. Pure copper, for instance, is used in many cases because it is an excellent conductor of heat as well as having good resistance to corrosion. These properties, together with its easy workability, are an ideal combination for many purposes. In such cases the use of bronze weld metal ensures strong ductile joints, free from troublesome porosity. Welding is easily carried out with a minimum of preheating, and any subsequent forming operations involving the weld metal can be carried out with confidence.

It should be noted in this connection that ordinary commercial copper, usually referred to in the trade as "tough pitch copper," is less suitable for welding by any process than deoxidised copper, which is now normally supplied for welding. Both types can be satisfactorily welded with "bronze" electrodes, but tough pitch copper is weak in the cast condition and consequently the zone near the weld tends to be lacking in ductility.

Brasses, most commonly the 60–40 copper-zinc alloys, are widely used in the form of castings. They include many high tensile materials which are essentially modified 60–40 brasses. The recovery of faulty castings and the repair of worn parts is a valuable service most readily carried out by metallic arc welding, because of the concentrated heat available. Provided the right electrode is used, the difficulty of zinc vaporisation, and subsequent weld porosity, is overcome and considerable savings in the reclamation of metal can be made.

Successful welding of copper alloys depends on the observation of a few elementary precautions, and the exercise of more care in preparation for welding than is usually considered necessary with steel. The parts to be welded should be carefully cleaned of all foreign matter, such as scale, moulding sand corrosion products, oil, water, etc., and even corroded metal which is apparently clean, and welding should always be commenced, if possible, on a cleanly cut metal surface. If it is suspected that some porosity exists beneath the surface to be welded which cannot be removed by cutting metal away, the job should be thoroughly dried before beginning to weld, otherwise the welding heat may vaporise moisture from the pores and the weld metal itself will be unsound.

A further point to be observed is that weld metal of this type is more fluid than steel weld metal, and where an open joint is being welded it may be necessary to support the under-side of the joint in order to prevent excess metal running through. When welding copper alloy, there is greater loss of heat than occurs with steel, and if this is not controlled a condition of adhesion rather than true welding may be obtained ; in such cases the weld metal may become detached in subsequent service. This can only be overcome by the use of preheating, but this must be used judiciously or the weld metal may become too fluid to control. No general rule can be stated, but in most cases it is possible to judge from the finish of the weld whether the metal has been hot enough. Preheating is more necessary with lightly coated than with heavily coated electrodes, and a few trials are usually sufficient to indicate the degree at which it is most effective.

Surface Hardness of Metals

ATTEMPTS to measure the hardness of thin layers, particularly of brittle materials, have met with little success, owing largely to the fact that a very small indentation is difficult to produce under standard conditions and difficult to measure accurately. Also, the properties of the underlying material may exert a profound influence on the result. Existing methods of measuring the hardness of metals in thin layers depend on (*a*) the scratch test; (*b*) the micro-indenter, in which a very light load is applied to a pyramid indenter, the size of the impression being measured with a microscope under a much higher power than is customary for hardness tests, and the indenter often being incorporated with the microscope; and (*c*) the micro-indentation test in which the indenter is fashioned to give a rhomboid shape of impression, the long diagonal of which is measured.

The efficiency of any method for examining the hardness of surfaces depends on the depth to which the effect of the test penetrates, or on the depth at which the properties affect the test. The actual depth of penetration can be regarded as a criterion, although the properties of the metal at a considerably greater depth are known to exert some influence on the test.

A new method of measuring hardness, developed primarily for thin electroplated coatings, is described by Dr. Chalmers,* but it has been found that the results relate to the properties of a very thin layer of the metal and are sensitive to the treatment to which the surface has been subjected. The author refers to the property measured by this new method as surface hardness and the test has a wider range of applications than was anticipated.

The new method is based on the principle that while it is difficult to apply a very small indicating force under accurately standardised conditions, it is possible to apply a very large number of such forces in such a way that, while each is not under control, the result is statistically definite. The procedure is to drop a large number of grains of sand, or particles of emery, from a fixed height on to the specimen. The particles are of varying shapes, and within the limits fixed by the screening of the sand, of varying size. They are, in addition, randomly orientated when they hit the surface. The impressions in the surface, therefore, vary widely in shape and size, but if a sufficiently large number of particles is used, the average shape and size of the pits depend only on the hardness of the material, while the number of indentations depends on the amount of sand used. It is therefore necessary to measure the average size of the indentations, and this is carried out by measuring the reduction in the specular reflectivity of the surface. For this purpose an instrument is described which consists essentially of two parts: a device for dropping known quantities of sand on the surface under examination from a known height, and means of measuring the specular reflectivity of the surface.

The procedure adopted in carrying out a measurement is described, and a full analysis of the method is given, together with a number of results which are detailed to show the various directions in which the method has so far been employed.

In his final discussion on the method, the author states that the testing procedure, although differing in many respects from the conventional methods, must be regarded as a type of hardness test, because it measures the resistance of the material to deformation. More specifically, the indentations are made by impact and not by static loading, and the material on which the test is made is a very thin layer near the surface; the hardness of the material nearest the surface has the greatest influence on the results of the test. Consequently the existence of a superficial layer with properties differing from those of the underlying material can be demonstrated.

Preliminary experiments have shown that the method may have useful applications in connection with the surface hardness of materials where other methods of measuring this property are unsatisfactory. Less practical importance but greater academic interest attaches to the use of the method for studying surface phenomena, of which one example is the effect of mechanical polishing on the hardness of the surface. The effect of heat-treatment on the polished layer may also be of some interest, particularly when the metal concerned is an alloy subject to age-hardening, temper-hardening or precipitation.

* Bruce Chalmers. *Jour. Inst. Metals*, 1941, **67** 295–314.

Apparent Relations Between Manganese and Segregation in Steel Ingots*

DISTRIBUTED through the many reports of the Committee on the Heterogeneity of Steel Ingots are to be found many descriptions of about seventy ingots, the extent of the segregation in which has been thoroughly investigated.[1] The ingots vary widely in size, their weights ranging from ½ ton to 172 tons, and since the utmost care has been exercised to ensure that, in each instance, the results should be trustworthy, the work may be considered as thoroughly representative of steelmaking practice. This large and costly collection of information invited more examination than had yet been given to it, in order to ascertain whether the data disclosed features connected with segregation other than those noted in the reports, and the above paper by J. H. Whiteley records an attempt made in that direction.

In plain carbon steels, which are alone dealt with, there are four segregating elements—viz., carbon, phosphorus, sulphur and manganese, and of these the first three are fairly consistent in their behaviour, but that of manganese is unmistakably erratic; in some ingots the increment is quite large, while in others it is comparatively slight, even when the segregation is obviously pronounced. The one or more underlying causes of this variability on the part of manganese are still obscure, and the primary object of the investigation was to elucidate this problem. As a result of the investigation four conclusions have been reached:—

(1) The ratio of the manganese increase to that of the sulphur is as a rule higher in sound than in unsound ingots;

(2) Carbon, phosphorus and sulphur may all carry some excess of manganese in segregating, their total atomic increments being directly proportional to the percentage increase of manganese in both sound and unsound ingots, although in the latter there is a lesser proportion of extra manganese, probably owing to gas evolution. The inference is drawn that all three elements exist largely as compounds of iron and manganese in the liquid steel near the freezing point;

(3) In sound ingots a linear relationship appears to obtain between the ratio of the increment of manganese to the total increment of carbon, phosphorus and sulphur and the ratio of manganese to these elements at position E (at the base of the cavity in the ingot head).

(4) Segregation is diminished as the ratio of the manganese to the carbon, phosphorus and sulphur in the steel is increased.

The author emphasises, however, that these conclusions should not be regarded as final; to establish them beyond question, they need more confirmation.

* Paper No. 8/1941 of the Committee on the Heterogeneity of Steel Ingots, Iron and Steel Institute, September, 1941. (Advance Copy.)

1 (*a*) First Report on the Heterogeneity of Steel Ingots. *Journal of the Iron and Steel Institute*, 1926, No. I, pp. 39–151.
(*b*) Second Report, *ibid.*, 1928, No. I., pp. 401–547.
(*c*) Fourth Report. Iron and Steel Institute, 1932. *Special Report* No. 2.
(*d*) Fifth Report. Iron and Steel Institute, 1933. *Special Report* No. 4.
(*e*) Sixth Report. Iron and Steel Institute, 1935. *Special Report* No. 9.

Classification of Copper and Copper Alloys—Part III

By H. J. Miller, M.Sc.

(*Metallurgist, Copper Development Association*).

Copper-base alloys embrace such a large number of different compositions, and their commercial nomenclature is so varied, that the whole industry might well standardise on fewer compositions. In this and two preceding articles the author presents a simplified method of classifying copper and its alloys which will greatly assist engineer-users and designers in their task of specifying materials.

FURTHER copper alloys are presented in this, the final, section of a series of articles giving tabulated data concerning the more important copper-base materials, with a citation of appropriate British specifications. It has only been possible to give brief details of properties which have been limited to tensile strength and related properties, and diamond pyramid hardness values of materials for annealed and work-hardened conditions, where applicable.

The tables which accompany the present section of the article are devoted to welding, bronze welding, brazing, and silver soldering materials (Table XIV); wrought nickel silver (Table XV); copper-nickel alloys (Table XVI); and silicon bronzes (Table XVII). As in the previous sections of the article, in the columns relating to mechanical properties, the suffix (A) refers to the annealed conditions, while the suffix (H) refers to the most fully work-hardened conditions which can usually be achieved in commercial production. The application of the heavy amounts of work required to achieve these latter properties are dependent to a large extent on the sectional dimensions.

The data call for little comment, but it should be realised that modifications of compositions and properties of these alloys are favoured by different producers; it is believed, however, that the information given will be invaluable to users under present conditions.

TABLE XIV.
WELDING, BRONZE WELDING, BRAZING AND SILVER SOLDERING MATERIALS.

Description.	Composition (%).					Approximate Melting Point, °C.	British Standards or other Specifications.	Remarks.
	Cu.	Ag.	Zn.	Sn.	Other Elements			
Copper for autogenous welding.....	99	0·5–1·0	—	—	0·1 P	1,075	—	In the autogenous flame-welding of deoxidised copper the presence of silver in the weld metal is helpful, and it is present therefore in most welding rods.
Copper-tin alloys for electric arc welding	92–96	—	—	—	Up to 0·4 P	850–1,000	—	Applicable to copper and copper alloys—a typical use is the repair of corroded or pitted manganese bronze components.
Copper-silicon alloys for electric arc and flame welding.	95–99	—	—	—	1–3·5 Si, 1 Mn or other elements.	—	—	Welding rods of silicon bronze alloys are sometimes employed for welding copper by electric arc methods, and also for copper-silicon base alloys by flame or arc methods.
Typical bronze welding alloys— (*a*)	60	—	40	—	0·25 Si	900	—	The oxy-acetylene process of bronze welding ferrous and non-ferrous materials has achieved considerable importance within recent years owing to its simplicity and efficiency; the method is especially applicable to copper. Alloy (*c*) containing nickel is a white coloured alloy which is used in conjunction with nickel alloys and in some instances for facing steel components.
(*b*)	60	—	39	1	0·25 Si	900	—	
(*c*)	45	—	45	—	10 Ni	950	—	
Brazing brasses— (*a*)	60	—	40	—	—	905	B.S. 263 Grade AA	The first of these brazing brasses is procurable in fine gauge forms, while the last is produced in granular form only, which facts frequently differentiate their uses; other important factors in selection are the composition and melting point of the parent material.
(*b*)	54	—	46	—	—	885	B.S. 263 Grade A	
(*c*)	50	—	50	—	—	870	B.S. 263 Grade B	
Special brazing alloys (*a*)	92	—	—	—	8 P	720	—	Alloys (*a*) and (*b*) have high fluidity, and are self-fluxing in character: they are particularly suitable for lap joints where considerable penetration is required.
(*b*)	90	5	—	—	5 P	710	—	
(*c*)	60	1	38	—	0·25 Si	890	—	
Silver Solders— (*a*)	29	61	10	—	—	735	B.S. 206 Grade A	Although there exists a wide range of silver solders, the groups here listed are in the greatest commercial use. To conserve in jointing material special attention should be given to joint design and spacing.
(*b*)	37	43	20	—	—	780	B.S. 206 Grade B	
(*c*)	15	50	16	—	19 Cd	630	B.S. 206 Grade C	

TABLE XV.
WROUGHT NICKEL SLIVER.

Description.	Composition (%).				Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Ni.	Zn.	Pb.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $4\sqrt{A}$.	Diamond Pyramid Hardness.		
Sheet and Strip— 10% Nickel Silver	63	10	27	—	4 (A)–20 (H)	7 (A)–38 (H)	22 (A)–45 (H)	4 (H)–65 (A)	65 (A)–220 (H)	790	The range of alloys becomes progressively whiter with increase of nickel content, although usually there is little advantage in exceeding 18% nickel except for decorative products in which maximum resistance to stain and tarnish is required.
12% Nickel Silver ...	63	12	25	—	4 (A)–20 (H)	7 (A)–38 (H)	22 (A)–45 (H)	4 (H)–60 (A)	68 (A)–220 (H)	790	
15% Nickel Silver ...	63	15	22	—	5 (A)–22 (H)	8 (A)–40 (H)	23 (A)–45 (H)	4 (H)–55 (A)	72 (A)–220 (H)	790	
18% Nickel Silver ...	62	18	20	—	5 (A)–22 (H)	8 (A)–40 (H)	24 (A)–45 (H)	4 (H)–52 (A)	75 (A)–220 (H)	790	
	55	18	27	—	5 (A)–24 (H)	8 (A)–45 (H)	24 (A)–55 (H)	1 (H)–48 (A)	75 (A)–240 (H)	—	Particularly valuable in spring applications.
20% Nickel Silver ...	62	20	18	—	5 (A)–22 (H)	8 (A)–40 (H)	24 (A)–45 (H)	4 (H)–50 (A)	75 (A)–210 (H)	790	
25% Nickel Silver ...	57	25	18	—	5 (A)–20 (H)	8 (A)–40 (H)	25 (A)–45 (H)	4 (H)–50 (A)	80 (A)–210 (H)	790	
30% Nickel Silver ...	57	30	13	—	5 (A)–20 (H)	8 (A)–38 (H)	25 (A)–42 (H)	4 (H)–48 (A)	85 (A)–200 (H)	—	
Machining or engraving type of alloy.	60	12–18	Rem.	1–2	5 (A)–18 (H)	8 (A)–55 (H)	24 (A)–40 (H)	5 (H)–50 (A)	72 (A)–180 (H)	—	The lead addition seriously interferes with working properties, and the impact strength is much lower than in the lead-free alloys.
Wire and Rod	All the above alloys are procurable in the form of cold-rolled and drawn rods, and, with the exception of the last alloy, in wire forms also. The properties which can be attained are largely dependent on sectional dimensions.										
Rods and Sections—	Many of the above alloys are obtainable in the form of rod and certain sections, and in addition the undergiven alloy is produced by extrusion.										
	44	10	44	2	7–10	12–18	32–38	20–35	100–150	—	The hot-working properties of this material are excellent, and it can be hot-stamped and extruded into complex shapes; it has a yellowish white colour.

TABLE XVI.
COPPER NICKEL ALLOYS.

Description.	Composition (%).		Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Ni.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $4\sqrt{A}$.	Diamond Pyramid Hardness.		
Copper-nickel alloys in strip, sheet, tube and other forms. (*a*)	95	5	—	—	17 (A)–30 (H)	5 (H)–50 (A)	65 (A)–120 (H)	—	This composition, and the 98/2 alloy which is also sometimes produced, can be regarded as toughened copper having slightly superior mechanical and corrosion resistant properties.
(*b*)	85	15	—	—	21 (A)–32 (H)	8 (H)–45 (A)	70 (A)–130 (H)	—	This is the lowest nickel-content alloy having a white colour.
(*c*)	80	20	—	—	22 (A)–35 (H)	8 (H)–45 (A)	75 (A)–140 (H)	—	This grade is recognised as the most suitable of the series for severe cold-working processes, and it is well known because of its use in bullet envelope manufacture.
(*d*)	75	25	—	—	25 (A)–39 (H)	8 (H)–45 (A)	80 (A)–150 (H)	—	The most important commercial use of this grade is for coinage.
(*e*)	70	30	—	—	27 (A)–42 (H)	8 (H)–45 (A)	85 (A)–160 (H)	—	The 70/30 alloy is of particular importance for condenser and cooler tubes on account of good resistance to corrosion.

NOTE.—The copper nickel series is homogeneous throughout the entire range, and there are many other well recognised alloys containing less than 70% of copper, but this composition has been taken as the limit for the purpose of this classification of copper-base alloys. All alloys throughout the series possess good hot- and cold-working properties, and with those containing up to 25% nickel it is possible to apply cold working reductions exceeding 90%.

TABLE XVII.

SILICON BRONZES.

Description.	Composition (%).					Typical Mechanical Properties.					British Standards or other Specifications.	Remarks.
	Cu.	Si.	Mn.	Fe.	Other Elements.	Limit of Prop., Tons/sq. in.	0·1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elongation % on $4\sqrt{A}$.	Diamond Pyramid Hardness.		
Silicon Bronzes (strip, sheet, and wire) (*a*)	96	3	1	—	—	4 (A)–20 (H)	6 (A)–40 (H)	23 (A)–50 (H)	5 (H)–65 (A)	70–210	—	The silicon bronzes possess excellent corrosion resisting properties and for this reason are favoured for chemical plant construction. The electrical and thermal conductivities are low, namely of the order of 6% for the 3% silicon alloy, and this fact is a help in welding either by flame or electrical methods. The alloys listed are only a few of those which are in commercial production under various proprietary names.
(*b*)	98	1·5	0·5	—	—	2 (A)–15 (H)	4 (A)–30 (H)	17 (A)–35 (H)	5 (H)–50 (A)	60–150	—	
Silicon Bronzes. Cast (*a*)	95	4	1	—	—	—	—	18–22	15–30	60	—	
(*b*)	92	3·5	0·5	1·8	2 Zn	—	—	20–25	12–20	60	DTD 355	

United States to Increase Manganese Production

High Manganese Concentrates from Low Grade Ores

NORMALLY, the United States produces only about 3% of her total needs of manganese ; the remainder of her supplies are imported from abroad, and Russia has been one of the principal suppliers, accounting last year for almost one-fourth of the total amount imported. Since the beginning of the present war, however, much experimental research has been in progress in an effort to increase production within United States territory, and considerable success has been achieved, but with the increased pressure upon Russian resources in her war with Germany, the United States has intensified her search within her borders for suitable ores and definite assurance of a possibility of greatly increased manganese production is given in a report by the Bureau of Mines, in which it is stated that concentrates have been produced with high manganese content ores from the low-grade deposits in the Las Vegas (Nev.) area.

Only high-grade ore, such as the Russian ore, containing 48% or more manganese, is generally used by American producers in making ferro-manganese, the form in which manganese is usually added in steel manufacture. Although few deposits of high-grade ore exist in the United States there are large reserves of low-grade ores, but these have been of no value in the current emergency because no feasible methods for successfully treating them to produce a suitable ferro-manganese have been developed. The Bureau of Mines has worked out a number of processes in the laboratory, however, and if these are proved successful by pilot plant tests, the United States will be able to supply the major part of her requirements from her own resources.

A pilot mill with a capacity of 40 tons of ore per 24-hour day has been put into operation at Boulder City, and the first ore to pass through it was that from the nearby Las Vegas Wash mining district. It is estimated that there are nearly a million tons of ore in this area containing more than 10% manganese, and that more is available in the adjacent Virgin River district. More than 3,600 tons of the Las Vegas ore has been mined and stored at the Boulder City plant. This ore, which is run of mine, averages about 18% manganese. Except for a small amount of high-grade material mined during the last great war, this reserve of manganese has been undeveloped, because until the Metallurgical Division of the Bureau of Mines started on its present programme the ore had resisted all attempts at concentrating it to an extent which would permit its use for the manufacture of ferro-manganese.

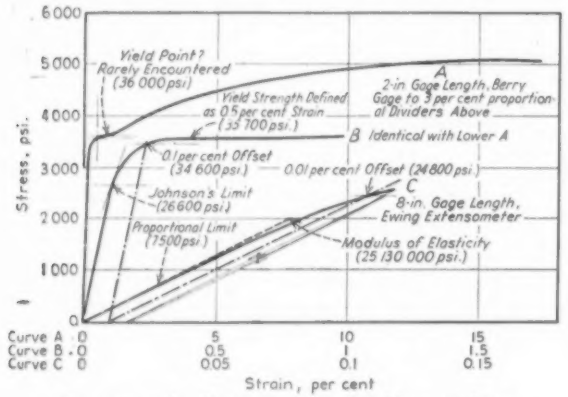
Earlier work had shown that flotation was feasible as a means of concentrating manganese carbonate ores, and a process similar to that is now in use by the large United States producer of manganese, the Anaconda Copper Co., at Butte, Montana. Modifications of methods now in commercial use for the flotation of oxide manganese ore failed to effect a separation of the Las Vegas ore.

Success in the treatment of this ore was first attained when a new reagent, DLT-958, was tried. This reagent, developed by a chemical company as a result of the laboratory investigations of the Bureau of Mines, was found to float the worthless gangue away from the manganese and leave the manganese in a form which, when sintered, met every requirement for material for the manufacture of ferro-manganese. Much of the credit for the successful practical demonstration of the ability to concentrate manganese ore from the Las Vegas district must therefore be given to the fact that the Bureau engineers were ready with DLT-958. Subsequent tests have shown that other reagents of similar characteristics may be used so that successful operation of the plant is not restricted to a particular reagent, but the importance of reagent development to the successful flotation of manganese ores cannot be too highly emphasised.

First returns, just in from the laboratory, show that the pilot plant operation confirms in every way the careful laboratory work of the Bureau staff, and the concentration of another large domestic deposit of manganese based on the work of the metallurgists has been demonstrated on a large scale. The product produced in the first operations analysed after sintering—52% manganese, 1% iron, 9% silica. The recovery from the ore was just over 70%. It is thought that the recovery may be increased as the operation of the plant is further perfected. Laboratory experiments have shown that the lead and copper present in concentrates of the Las Vegas ore can be eliminated by a roasting treatment. Operations will be continued at the pilot plant to determine complete data concerning costs. The circuits in the plant will then be revised and other ores which are on hand at the plant will be studied. More than 10,000 tons of ores from widely separated localities are available. In addition to the pilot mill, the Boulder City plant has an extremely versatile hydrometallurgical plant and a small electrolytic manganese plant.

Stress-Strain Diagram of Malleable Cast Iron

THE form of the stress-strain curve for malleable cast iron has been rather frequently investigated, but a new aspect of the subject is presented by Schwartz and Junge in the October *Bulletin* of the American Society for Testing Materials. In connection with the work of the authors on Young's modulus of elasticity and some related properties of graphite materials,* it appeared opportune to investigate the form of the complete stress-strain curve. Since the modulus of elasticity cannot be satisfactorily determined on unmachined specimens, it seemed desirable for purposes of comparison to use machined specimens for the preparation of this stress-strain curve also, even though an unmachined specimen is customarily used for acceptance testing. In that connection it was occasionally noted that the stress-strain curve had a somewhat unusual form, as shown in the accompanying illustration. The curves A, B, and C of this figure are identical except for the scale used for the strain. In about three-eighths of the cases observed there is a slight inflection which might almost be interpreted as a yield-point.


Yield Point? Rarely Encountered (36 000 psi.)
Yield Strength Defined as 0.5 per cent Strain (35 700 psi.)
2-in. Gage Length, Berry Gage to 3 per cent proportional Dividers Above
A
B Identical with Lower A
0.1 per cent Offset (34 600 psi.)
0.01 per cent Offset (24 800 psi.)
Johnson's Limit (26 600 psi.)
Proportional Limit (7500 psi.)
C
8-in. Gage Length, Ewing Extensometer
Modulus of Elasticity (25 130 000 psi.)
Stress, psi.
6 000
5 000
4 000
3 000
2 000
1 000
0
Curve A 0 5 10 15
Curve B 0 0.5 1 1.5
Curve C 0 0.05 0.1 0.15
Strain, per cent

Stress-strain diagram of malleable cast iron.

This point is observed only on machined specimens, the diameters of which at any section rarely varied by more than 0·0005 in. in a nominal 0·505 in. diameter and then only if the specimens are perfectly straight (not more than a few thousandths of an inch out of line at the centre). It cannot be detected unless readings are taken at very close intervals, 0·002 in. per inch of strain or 250 psi. of stress. It is our impression that when it is not found the reason is that it is obscured (*a*) by lack of straightness; (*b*) by lack of uniformity of cross-section, and (*c*), most important of all, by the fact that the decarburised zone has a different stress-strain relation from the undecarburised zone causing the extensometer to read a sort of integration of many stress-strain relationships unless the decarburised zone has been completely removed. The existence of this point of inflection has been confirmed in the Cleveland laboratories of the Aluminium Company of America using the Templin autographic apparatus. They find this point with about the same frequency as we do.

The illustration already referred to is typical of many such curves, and is no doubt self-explanatory. To the best of our knowledge and belief unmachined specimens will never give this form of curve.

* H. A. Schwartz and C. H. Junge. Proceedings Am. Soc. Testing Mats. vol. 41, 1941.

EXPERIENCED ESTIMATOR required to take charge of the Estimating Dept. of a Steel and Non-ferrous Foundry in the Midlands. Give fullest detail of previous experience, age and salary required. Box 200.

A Stress-Strain Curve for the Atomic Lattice of Aluminium

A TECHNIQUE has been developed for obtaining the stress-strain curve of the atomic lattice of a metal at the same time as the external stress-strain curve obtained in normal mechanical testing. This lattice stress-strain curve gives the displacement of the atoms from their normal positions in the atomic lattice and the extent of their recovery when at any point the applied stress is removed. The work, which has been carried out as part of a research programme of the National Physical Laboratory, constitutes a direct attack upon the problem of internal strains. An investigation of this type on aluminium, of 99·7% purity, subjected to tensile stress, is described by Dr. W. A. Wood and Dr. S. L. Smith.*

The apparatus employed consists essentially of a combined tensile testing machine and X-ray back-reflection spectrometer. The changes in external dimensions are given in the usual way by an extensometer attachment. The changes in a selected atomic spacing, measured in a direction perpendicular to the applied stress, are given by changes in diameter of a sensitive X-ray diffraction ring reflected from the specimen whilst under stress. The principles of this apparatus have been described in another paper.[1]

The stress-strain curve obtained for the atomic lattice of aluminium subjected to tensile stress gives the displacement of the atoms from their normal positions on a selected set of atomic planes. The planes chosen are those with spacing practically perpendicular to the applied tensile stress, which should contract in conformity with the external contraction of the cross-section of the tensile test-piece as the specimen is stretched. It is shown that up to the external yield-point the contraction in lattice spacing is directly proportional to the applied stress. Beyond the yield stress, the lattice contraction slows down and the spacing rapidly reaches a limiting value. At stresses approaching the ultimate the lattice actually tends to expand.

A further set of experiments, in which cycles of stress were employed, shows that when a stress greater than the yield is employed, the contracted lattice spacing, instead of expanding back to its original value, passes through that figure and reaches a permanent value in excess of the original. The lattice is left with a permanent expansion which increases in a regular manner with the value of the stress applied; a process which explains the unexpected shape of the lattice stress-strain curve, and reveals the presence of a fundamental factor, hitherto unobserved, in the mechanical deformation of metals,

The Bristol Engineering Manufacturers' Association

MANY towns and districts could emulate with profit the Bristol Engineering Manufacturers' Association, which has now been functioning for about five years. This live association was formed to provide a publicity organisation for making Bristol's engineering activities more widely known, and the promotion of mutual assistance among members is its first concern. It subscribes to the Bristol Development Board, and is the official advisory body on engineering to that Board.

This Association acts as a medium on engineering matters between the trade and Government Departments, Civic Authorities, Chambers of Commerce, national and local press. It provides an information bureau which is widely used by industrial concerns in all parts of the country, and publishes a very informative *Bulletin*, though it is doubtful whether this publication will continue because of paper difficulties. A very useful directory is also issued and sent to all industrial concerns in the West of England and other selected centres. The hon. secretary is Mr. J. E. Evans, 104, Filton Avenue, Bristol, 7.

* W. A. Wood and S. L. Smith. *Jour. Inst. Metals*. 1941, **67**, 315-324.
1 S. L. Smith and W. A. Wood. Proc. Roy. Soc. 1940, [A], **176**, 398.

Silver Plating

Electroplating silver on other metals has been practised over a hundred years. The cyanide bath was one of the first proposed, and with slight modifications is the standard silver bath to-day. Both the potassium silver cyanide and the sodium cyanide baths are in commercial use. A relatively new silver cyanide bath, which is gaining in popularity, is that containing from 11 to 15% potassium nitrate. Full operating details, based on modern practice, are detailed and discussed in a report by Promisel and Wood from which this article has been abstracted.*

THE origin of electro-deposition is closely related to the birth of the electroplating industry itself, which occurred at the latter part of the first half of the nineteenth century. The earliest patent granted for the application of the principles of electro-deposition for decorative purposes is credited to Elkington and Barratt in 1838. Two years later, Elkington was granted a patent for silver-plating, and it is symbolic of the value of the original electroplating formulæ and the "staidness" of the plating industry that this early patent described essentially the most popular modern silver-plating bath—that is, the double cyanide bath with excess cyanide.

In the hundred years that have elapsed since Elkington, numerous investigations have dealt with variations of his formula, together with many novel ones; it is noteworthy, however, that in spite of all the laborarory and plant trials of various silver-plating baths, the outstanding and almost universal bath in industrial use to-day is the bath containing silver cyanide, together with an excess of sodium or potassium cyanide, some sodium or potassium carbonate, and small amounts of the brightener, carbon disulphide. It is due to the superiority of this bath over all others tried, resulting from its simplicity, stability, ease of operation, favourable electrochemical properties, and the attractive appearance of deposits, that it is the generally accepted silver-plating bath to-day. It is noteworthy also that the double cyanide bath containing potassium nitrate is in growing use.

Present-day investigations devoted to silver-plating are not so much concerned in finding radically new types of solutions, though such work is in progress, as they are in modifying the present cyanide bath in order (1) to permit use of higher current densities with this bath without sacrifice in appearance of the silver deposits; to improve the throwing power in order to secure better distribution of the deposit; (2) to control the corrosion of silver anodes; and, especially (3) to apply mechanical equipment to silver-plating, such as plating machines, automatic filtration, anode and cathode agitation, and more efficient racking methods. It is from this study of mechanical details in particular that most of the progress in commercial silver-plating may be expected in the near future.

Functions of Constitution of Bath

By far the greater majority of cyanide silver solutions are made with silver cyanide as the source of metal ions. Regardless of the manner in which silver enters the plating bath, whether through silver cyanide additions or through the dissolution of silver anodes, its solubility and degree of ionisation depends upon the presence of sodium or potassium cyanide, which forms with the silver a soluble complex anion predominantly $Ag(CN)_2$. Chemical calculations are therefore based on a ratio of two molecules of the alkali cyanide to one atom of silver. The greater the excess of alkali cyanide (usually called "free cyanide") above that required to form the anions, $Ag(CN)_2$, the greater the decrease in the concentration of the silver cation. However, the customary silver cation concentration is essentially independent of small changes in the metal concentration within the usual bath-operating range.

* N. E. Promisel and D. Wood, The Electrochemical Society, 1941. Advance copy.

The electrical conductivity of the silver-plating bath is commonly raised by the addition of sodium or potassium cyanide and sodium carbonate. None of these affects the conductivity only. The free cyanide, besides serving as a complex anion builder, increases the cathode polarisation, makes possible good corrosion of the anodes and favourably affects the physical properties of the deposit. The sodium carbonate also exerts an appreciable effect: It increases cathode and anode polarisation, and also modifies the physical properties of the plate. Some improvement in conductivity of the bath is caused by increasing the silver ion content, which simultaneously decreases cathode polarisation.

Of the other ions that occur in silver-plating solutions, the two that have received greatest consideration are sodium and potassium, the relative merits of which have long been argued. It has been shown[1] that the cathode polarisation at which so-called "burned" deposits occur is lower in sodium solutions than in potassium solutions. This is one major reason for the general preference which exists for the potassium cyanide solution, since higher current densities and, therefore, faster plating are thus permitted with it. The solubilities of the respective carbonates are also important. Due to the much greater solubility of sodium carbonate in the silver-plating bath at high than at low temperatures,[2] difficulty is sometimes experienced whenever a plating solution high in this salt is allowed to cool. At such times small crystals of sodium carbonate may form and anchor on to the cathode itself, causing faulty silver deposition. Another undesirable property of the carbonate ion is the tendency, when a slightly high concentration has been reached [38–75 g./L. (5–10 oz./gal.)], to cause an abrupt rise in cathode polarisation upon a small decrease in bath agitation under otherwise normal operating conditions. This condition frequently results in "burned" deposits. Because of the above objections, sodium carbonate is most safely held below 43 g./L. (6 oz./gal.), while the concentration of potassium carbonate may safely be permitted to reach 113 g./L. (15 oz./gal.). Since the latter is approximately the equilibrium value between dragout in commercial plating and chemical formation from cyanide[3], the advantage in this respect of using the potassium salt instead of the sodium becomes evident. Other advantages in using potassium rather than sodium salts are improved conductivity of the bath and brighter deposits that are more readily obtained. The only significant advantage in the use of sodium salts is the lower cost as compared with potassium.

Carbon disulphide is the only addition or brightening agent known to the authors to be in current commercial use. It is invariably added to the bath as a solution or suspension made by taking a small sample of the plating bath or a fresh potassium cyanide solution and dissolving the carbon disulphide in it. Although it is possible, using this brightener, to produce nearly mirror-bright deposits under ideal conditions, it is more common practice to add only enough of the brightener to produce semi-bright

1 Egeberg and Promisel. Trans. Electrochem. Soc. **59**, 287 (1931).

2 This is a universally recognised fact, but numerical values are not available. However, in pure water, sodium carbonate dissolves to the extent of 7·1% at 0° C.; and 45·4% at 100° C.

3 Carbonic acid from the atmosphere is absorbed by the bath and reacts to form carbonates:—

$$2NaCN + H_2O + CO_2 = Na_2CO_3 + 2HCN$$

deposits. Such deposits are finished with little more effort than is required for the brightest obtainable and even in the latter case some finishing or buffing operation is usually necessary anyway. On a single cathode of irregular shape, such as a teaspoon, it is possible to have many degrees of brightness, varying sometimes in sharply defined bands, with differences in agitation or current distribution. Because of such possibilities, it may be said that successful silver plating is largely a matter of arranging other factors to provide a suitable condition at the cathode for the most uniform effect of the brightener over the entire surface.

The most commonly used silver-plating solution contains :

Silver (as metal)	25–33 g./L. (3–4 troy oz./gal.)
Free potassium cyanide	30–45 g./L. (4–6 oz./gal.)
Potassium carbonate	30–90 g./L. (4–12 oz./gal.)
Carbon disulphide brightener as needed	up to 0·9 mg./L. (0·0001 fl. oz./gal.)

A concentration of silver higher than 33 g./L. may be employed where the added cost is compensated for by higher limiting current density, which may be obtained under carefully regulated, favourable operating conditions. On the other hand, a large increase in silver content of the bath has an adverse effect on its throwing power, and, to some extent, on anode polarisation ; below 25 g./L. of silver, however, a lower current density range becomes necessary, but this is sometimes acceptable where the resulting greater throwing power is required. Furthermore, a silver content below 25 g./L. may be advisable also in the interest of economy where large silver losses due to dragout is a serious problem.

Below 38 g./L. (5 oz./gal.) of free potassium cyanide, anode polarisation rises rapidly, regardless of metal or carbonate concentration. More than 38 g./L. of free cyanide is usually required to maintain satisfactory anode corrosion. The free cyanide content may be raised appreciably above 38 g./L. without affecting the appearance of the silver plate , furthermore, throwing power is improved and higher current densities are permissible under otherwise favourable conditions. On the other hand, under some conditions, a large excess of free cyanide will reduce or completely destroy the effect of the brightener, carbon disulphide. A noticeable effect in the behaviour of the brightener may be expected, at a free cyanide concentration above 60–68 g./L. (8–9 oz./gal.). There are other bath variables besides free cyanide concentration that influence the behaviour of the carbon disulphide.

Potassium carbonate is added when making up a new solution to improve the otherwise poor bath conductivity and to increase cathode polarisation and resulting throwing power. Potassium carbonate is the normal decomposition product of potassium cyanide and its concentration tends to increase on continued operation and ageing of the bath. In the case of commercial installations potassium carbonate increases gradually up to the neighbourhood of 113 g./L. (15 oz./gal.), at which approximate value it reaches an equilibrium between formation by decomposition and loss through dragout.

Solutions are frequently made with sodium cyanide and sodium carbonate where economy prohibits the more expensive potassium salts. The following concentration ranges are typical :—

Silver (as metal)	25–33 g./L. (3–4 troy oz./gal.)
Free sodium cyanide	30–38 g./L. (4–5 oz./gal.)
Sodium carbonate	38–45 g./L. (5–6 oz./gal.)
Carbon disulphide brightener	0·9 mg./L.

The only major difference in desirable range of concentrations between this sodium cyanide solution and the potassium solution specified above is in the carbonate content. The undesirable effects of high concentrations of sodium carbonate have been previously noted, and it may be mentioned that by limiting a silver-plating solution to this lower total carbonate content, bath conductivity is sacrificed and throwing power of a lower order results.

Sodium salts, cyanide and carbonate, and not potassium salts, are used almost universally for " strike " solutions. The most common " strike " solution for basis metals other than steel contains :—

Silver (as metal)	3–4·5 g./L. (0·4–0·6 troy oz./gal.)
Free sodium cyanide	60–90 g./L. (8–12 oz./gal.)
Sodium carbonate	8–30 g./L. (1–4 oz./gal.)

Steel is now rarely plated directly with silver, but when such is the case a " first strike " is used, such as :—

Silver (as metal)	¾–1½ g./L. (0·1–0·2 oz./gal.)
Free sodium cyanide	50–150 g./L. (8–20 oz./gal.)

The combined effect of reducing the silver concentration of the first " strike " formula and of increasing the free cyanide is to decrease the silver ion concentration to an extremely low value which supposedly ensures good adhesion of the deposit on steel.

The following silver-plating solution, which is slightly different from the conventional ones, is in limited but in increasing use to-day :—

Silver (as metal)	16–18 g./L. (2·0–2·3 oz./gal.)
Free sodium cyanide	15–22 g./L. (2·0–3·0 oz./gal.)
Sodium carbonate	max. 22 g./L. (max. 3·0 av. oz./gal.)
Potassium nitrate	113–150 g./L. 15–20 av. oz./gal.)

In spite of the lower range of silver concentration specified, the current density range is at least as high as with the higher silver concentration range in the conventional bath.

In potassium nitrate-cyanide solutions such as the above, anode corrosion appears to be due in part to the nitrate ion.[4] This allows a lower range of free cyanide concentration as against the nitrate-free baths, even in the presence of carbonate, which latter has an adverse effect on anode corrosion. In presence of the nitrate, brighter deposits under favourable operating conditions are usually possible at or even below the lower limit of free cyanide specified. Satisfactory anode corrosion may be had at as little as about 7½ g./L. (1 oz./gal.) of free cyanide. Concentrations of free cyanide higher than 22 g./L. (3·0 oz./gal.) have no adverse effect except where maximum brightness is needed ; they are accompanied by slight improvement in throwing power and covering power.

In principal, this nitrate-cyanide bath contains no carbonate to begin with. Carbonate is, however, formed in the bath and, at a concentration above about 22 g./L. (3 oz./gal.), maximum brightness is no longer obtainable. However, up to this value, 22 g./L., the carbonate may be considered as a tolerable impurity. When maximum brightness is unimportant, the presence of a higher carbonate concentration may be accepted as contributing to higher cathode polarisation with improved throwing power.

In the nitrate-cyanide bath the potassium nitrate has a beneficial effect on the appearance of deposits and on the operation of the bath. Sodium nitrate, on the other hand, when used in place of the potassium salt, produces a very undesirable plating solution. As in the case of carbonate, a low concentration of sodium ions may be tolerated, allowing the use of a sodium cyanide at the low concentration required. In addition to contributing much of the total conductivity of the bath, potassium nitrate is the only source of potassium ions when sodium cyanide is used. For this reason, the potassium nitrate concentration must be kept high relative to the total sodium salt concentration.

Maintenance and Control

In silver-plating baths, as in other baths, filtration of the bath is resorted to as a specific cure or treatment for rough deposits. Periodic filtration is a common preventive measure, with intervals varying from six months in some plants to one month in others. Where frequent filtration is practised, it is usually directed toward removal of particles of colloidal dimension or close to it. For this purpose, a filter-aid, generally diatomaceous earth, is used. This type of filtration is based on and supports the theory that carbon disulphide brightener produces a solid colloid phase in solution. When brightness of plate falls off in spite of the usual brightener additions, and under otherwise normal conditions, filtration with diatomite is resorted to,

4 Silver may be stripped electrolytically from steel in a solution containing only potassium nitrate and ammonium hydroxide.

to remove the agglomerated solid colloid product. By this procedure the normal colloid phase is likewise removed, as is indicated by the fact that a plating solution producing bright deposits ceases to do so after diatomite filtration. Furthermore, the plating solution again performs normally, producing acceptable bright plate, upon adding fresh quantities of carbon disulphide after diatomite filtration. Continuous filtration, coupled with continuous brightener addition, appears to be a logical and desirable procedure. That this is not in general use may be due to the difficulty of avoiding introduction of air into the bath during filtration. Air has a distinctly undesirable effect in tending to produce pitting of the silver deposit. Furthermore, filtration must necessarily be thorough and rapid, for if not stirring up residual particles during filtration will usually give rise to rough silver deposits.

In most plants there is no serious problem in silver plating, as there is in nickel plating, due to the presence of impurities. Although little is known of the effect on silver plate of foreign metals, no difficulties are traced to any, with the possible exception of iron. This metal may reach a high concentration in the plating bath and has been observed to cause a yellowish tint in the silver deposit.

In silver-plating practice to-day the maintenance and control of the baths are based primarily on chemical analyses and on the appearance of the deposit. The former determines the maintenance and control of the concentration of silver, free cyanide, carbonate and metallic impurities. Physical appearance of the plate determines the addition of the carbon disulphide, which is the only other bath ingredient ever considered. Other tests, occasionally made on silver-plating solutions, are the determination of anode and cathode polarisation. However, these tests are not of the routine type, but are in the nature of special tests to assist in determining the cause of occasional plating results which are unsatisfactory without apparent cause.

Tantalum

By L. Sanderson

Tantalum is one of the rare metals which is slowly finding many applications, and these notes briefly review information regarding its discovery, principal sources and application.

TANTALUM was first discovered in the form of an oxide containing an unknown element in a Finnish mineral. The discoverer was A. K. Ekeberg, but at that time he was unable to separate the element. It was rediscovered, again in an oxidic form, but this time in a Bavarian mineral, by H. Rose, in 1844. It was not until 1902, however, that tantalum, as Ekeberg called his unknown element, perhaps because his inability to isolate it was tantalising, came nearer to being separated as a metal. This was when H. Moissart obtained a carbon-containing metal by fusing the pentoxide with carbon in the electric furnace. In 1905, however, the pure metal was at last achieved by W. von Bolton, who fused an impure metal, obtained by an earlier process, in the electric furnace, excluding all air.

The principal sources of tantalum are the minerals tantalite and mangano-tantalite. Other sources of less important character are columbite, fergusonite, samarskite, euxenite, tapiolite, ixiolite, and microlite. Another newer source is bismuto-tantalite, which occurs in Uganda. Practically, Australia and Nigeria are the chief sources of tantalum ores, though deposits of tantalite and columbite are known to exist in many other countries—e.g., Canada, the United States of America, Brazil, Japan, Russia, etc.

As a rule, tantalum deposits are dressed on the spot by a small plant comprising crusher, jigs, and concentrating table. In Western Australia, the concentrate comprises clean mangano-tantalite with a little spessarite and a small quantity of scheelite. This is made up of Ta_2O, 68% ; Nb_2O_5, 14% ; MnO, 13% ; FeO, 2%.

Tantalum minerals are mostly found in pegmatites, particularly those types in which the predominating felspar is albite, and in quartz veins in close proximity to granite. Tantalite is usually found in association with columbite. One peculiar feature of this metal, tantalum, is that it is not found in nature in a compound with sulphur. Tantalite itself is an end-member of an isomorphous group of tantalates of iron and manganese. These crystallise in the orthorhombic system, but are often found in massive form. As a general rule, their hue is brown-black, and they are opaque, though red-brown translucent types are known. The specific gravity is about 8, which enables the tantalum content of the ore to be simply determined. Mangano-tantalite is a tantalite containing a good percentage of manganese. A characteristic ore of this type contains :—

Ta_2O_5	Nb_2O_5	SnO_2	TiO_2	FeO	MnO	MgO
%	%	%	%	%	%	%
68·65 ..	15·11 ..	0·48 ..	0·40 ..	1·63 ..	14·15 ..	0·15

Originally, the demand for tantalum was only small, but it has steadily grown. Western Australia, for example, produced only 5 long tons in 1923, as against about 20 long tons in 1937. Nigeria produced 759,000 lb. in 1936, as against 1,606,000 in 1937.

Tantalum is produced commercially in only Germany and the United States. One method of production of commercial importance may be outlined. A tantalate comprising 60% of tantalic oxide with a small amount of niobic oxide is used, the titanium, tin and other contents being minimised. The ore, generally a concentrate, is reduced to a fine powder fused with caustic potash. In this way, soluble tantalates are produced and extracted with water. The tantalates are precipitated from this solution by boiling it with sulphuric acid. When washed with water, this precipitate is dissolved in hydrofluoric acid. Sufficient potassium oxide is added to this acid solution to create a virtually insoluble double fluoride of tantalum and potassium. Separation is carried out by fractional crystallisation. Another method, suggested by Balke, is to reduce the double fluoride with metallic sodium or potassium, but this method is not recommended unless carried out in a vacuum with the crucibles containing the mixture placed in a tube or furnace which can be evacuated before the mixture attains the temperature of reaction. If this is not done, the metallic powder produced will be impure. The produce thus obtained is then treated with water or mineral acids so as to remove impurities. The metallic powder obtained is compressed into bar form, heat-treated, and ultimately fused in a vacuum furnace to remove any remaining impurities.

When ready to be marketed, the metal is in either bars, sheets, or wire, or even lap-welded tubes. It is ductile, and can be mechanically worked. The wire can be produced down to 0·001 in. and sheets are obtainable 0·002 in. in thickness.

The metal, tantalum, is rather darker than platinum, and about as hard as mild steel. In the commercial form it is 99·5% pure. At normal temperatures it is not subject to atmospheric corrosion, but oxidises quickly when heated to temperatures over 400° C. Its atomic weight is 181·36, and its melting point 2,850° C., one of the highest melting points of all metals. Its specific gravity ranges from 14·0–17·0, according to whether it is in powder or wire form. It gives in the form of wire a maximum stress of about 58 tons per sq. in., and has a coefficient of expansion rather lower than that of platinum, but higher than that of molyb-

denum or tunsten, being $6{\cdot}5 \times 10^{6}$- per 1° C. Electrical resistance for a wire 1 mm. long × 1 sq. mm. cross-section is 0·155 ohm.—i.e., approximately eight times that of copper, or three times that of tungsten.

An expensive metal to buy, its uses are naturally restricted, and as it has to be produced in a vacuum, it is difficult to see how it can ever become a low-priced material. Nevertheless, it has uses of no mean importance. It was, and to some extent still is, used for electric lamp filaments, but only where its added toughness gives it an advantage over tungsten filaments in resistance to vibration. Here again, however, it must only be used for d.c. current, as on a.c. systems it disintegrates as a result of crystallisation. Being hard and non-rusting, it is also used for surgical and dental instruments, hypodermic needles and spatulas. Certain small tools, as well as watch springs, spectacle cases, and the like, have been made from it, but the market for these is small. A more important use is in the making of spinnerets for artificial silk production. The tiny holes in these are as small as 0·0002 in. in diameter, and can be hardened by depositing a film of oxide that keeps them at constant diameter.

Tantalum is also used for the electrodes and sustaining wires in radio valves; for laboratory apparatus as a substitute for platinum; for the nozzles of sausage-skin-making machines; for the linings of chemical plant; for corrosion-resisting pump parts, etc. In tubular form it has been used for aeroplane fuel pipes. In the form of electrodes, it is used for the tubes of neon signs, and can be substituted for silver in arcing contact tips for electrical switchgear; It is used as a cathode in electrolytic analysis of metallic salts. It is, in fact, an ideal cathode material, being strong and rigid, long-lasting, and, as compared with platinum, cheaper and more efficient. It is not suitable for anodes because of its liability to rapid oxidation. This very fact renders it suitable for rectifiers in wireless apparatus, and the latter constitute one of its main outlets.

Some attempt has been made of recent years to use the carbide of tantalum as a tipping material for cutting tools, as it has great hardness, the intention being to substitute it for tungsten carbide. Up to now, however, there is no clear indication that it is in any considerable respect superior to the latter for this purpose.

The alloying of tantalum with other metals is quite feasible. The principal alloys are tantalum-iron, tungsten-tantalum, and tungsten-molybdenum. Ferro-tantalum (70% tantalum), to which some niobium has been added, is used to a certain degree in steel manufacture as an alloy designed to confer hardness. Here again, however, while it increases the elastic limit and breaking strength of the steel, it shows as a cutting alloy tool steel no superiority over the tungsten high-speed steels, while costing more. Its use as a corrosion-resisting metal when alloyed with iron has been known, but has not developed because of the lower cost and greater applicability of the rustless irons and steels. An alloy of 30% of platinum and 20% of tantalum is used for acid resistance, while tantalum nitride is sometimes used for coating the tungsten wire of electric lamps, enabling them to be run at a lower temperature than when uncoated, and thereby lengthening filament life.

The Ladle Cooling of Liquid Steel

THE development of the Schofield-Grace method of liquid-steel temperature measurement has made possible a very accurate control of temperature in the melting furnace. From the foundry angle it is equally important to know the temperature at which the metal is cast and to be able to so control the tapping temperature that a predetermined casting temperature is obtained. Between tapping and casting there is a fall in temperature of between 50° and 150° C. according to the ladle conditions. The objects of a recent paper by Land* are to obtain a clearer understanding of the mechanism of cooling in the ladle and to determine how the magnitude of the cooling is affected by the dimensions of the ladle, the physical properties of the refractory lining, and the preheating treatment which it has been given. With this information available the fall in temperature between tapping and casting under given conditions can be predicted with confidence.

A simple experiment with a model shows how the metal in the ladle cools by a relatively thin layer of metal passing down the vertical walls of the refractory lining and forming a reservoir of cool metal at the bottom of the ladle. The amount of the heat extracted by the ladle refractories is calculated, and particular attention is drawn to the effect of preheating the ladle. The author deduces that to obtain efficient preheating, the preheating period must bear a definite relation to the time taken to tap and cast. The results of the investigation are presented in the form of a table, which gives the drop in temperature for different sizes of ladle and different times of tapping and casting. This is reproduced in the accompanying table. It is shown that the effect of varying the tapping temperature and the temperature to which the ladle is preheated can be allowed for by multiplying the figures in the table by a simple factor. A second table gives corrections which may be applied for different methods of casting and for the time that the metal is held in the ladle between tapping and casting. The theory developed goes far to explain certain unexpected results in observed casting temperatures. The author also outlines the conditions for obtaining a uniform casting temperature. An Appendix summarises the mathematical approach to the problem.

* T. Land. Paper No. 1/1941 of the Steel Castings Research Committee, submitted to the Iron and Steel Institute. (Advance copy.)

TABLE I.

DIFFERENCE BETWEEN TAPPING TEMPERATURE AND MEAN CASTING TEMPERATURE (° C.).

The Table is correct for a difference of 1,000° C. between ladle temperature and tapping temperature.

Weight of Metal in Ladle.	Time (T) from Commencing Tapping to Finishing Casting. Min.																					
	1.	1¼.	2.	3.	4.	5.	7.	10.	12.	15.	18.	20.	25.	30.	35.	40.	45.	50.	60.	70.	80.	90.	120.
1 cwt.	106	122	150	183	212	237	280																
2 „	84	102	118	145	167	187	221	267															
5 „	62	75	87	107	123	137	163	195	213	238													
10 „	49	60	69	85	98	109	129	155	170	190	208	219	245	268									
1 ton	—	48	55	67	78	87	103	123	135	150	165	173	194	212									
2 tons	—	—	43	53	62	69	81	97	107	119	131	137	154	169	182	195							
3 „	—	—	—	47	54	60	71	85	93	104	114	120	134	147	159	170	180	190	208				
5 „	—	—	—	39	45	51	60	72	79	88	96	102	113	124	134	143	152	160	176				
7 „	—	—	—	35	41	45	54	64	70	79	86	91	102	111	120	128	136	143	157				
10 „	—	—	—	31	36	40	48	57	62	70	77	81	90	99	107	114	121	127	140				
15 „	—	—	—	27	31	35	42	50	55	61	67	70	79	86	93	100	106	112	122				
20 „	—	—	—	25	29	32	38	45	50	55	61	64	71	78	85	91	96	101	111				
25 „	—	—	—	—	—	—	—	42	46	51	55	59	66	73	79	84	89	94	103				
30 „	—	—	—	—	—	—	—	40	43	48	53	56	62	68	74	79	84	88	97				
40 „	—	—	—	—	—	—	—	36	39	44	48	51	57	62	67	72	76	80	88	95	101	107	124
50 „	—	—	—	—	—	—	—	—	—	41	45	47	53	58	62	67	71	75	82	88	95	100	115
75 „	—	—	—	—	—	—	—	—	—	36	39	41	46	50	54	58	62	65	71	77	82	87	101
100 „	—	—	—	—	—	—	—	—	—	—	—	38	42	46	50	53	56	59	65	70	75	80	92

Washing After Welding Magnesium Alloy Components

By E. E. Halls

The removal of chemical flux from welded magnesium alloy components is very important to preserve their serviceable life; the design of the parts welded and the technique employed in the process affect the achievement of this operation. The subject is briefly discussed, in which the underlying principles of the flux problem are stressed.

THE washing of welds in the magnesium alloys in order to remove chemical flux completely is even more important than it is in the case of the aluminium alloys. The fluxes employed for flame welding are of necessity of a corrosive nature, and although proprietary fluxes are available which are nicely balanced to do an effective fluxing job with due attention to degree of flow and minimised chemical activity, nevertheless the highly electro-positive nature of magnesium is such that rapid reaction with the flux occurs. According to the nature of the conditions to which the welded area is exposed so it will either corrode right away or deteriorate sufficiently to cause failure from loss of mechanical strength. Consequently the whole of the flux employed in welding must be completely removed from the job, and this elimination must be achieved immediately the weld is completed.

In order to render this practicable, the design of the parts for welding and the welding technique must be correct in order to avoid any possibility of including the flux in pockets, seams or overlaps.

Reviewing the procedure from the beginning, the first essential is to have the work in a thoroughly clean condition—that is, any oil, grease, paint, dirt, swarf, etc., must be thoroughly removed from the job, and in the locality to be welded even the protective chromate film which is normally on magnesium alloy stock as purchased must be removed. Otherwise the flux has more work to do than it is designed for, and the resultant products from the cleaning by flux may cause the latter to become sluggish and fail to flow to where it is required. A subsidiary result of this is the inclusion of the resultant fluxed products in the junction with consequent direct loss of strength and the almost certain corrosion from within with further deterioration gradually increasing in extent. The same applies to the welding rod, and the final cleaning in all cases should be done immediately before the welding operation. In most cases it can effectively be achieved using either a wire brush or abrasive paper.

The flux employed for the job should not be any flux designed for light alloys, but should be one properly prepared for magnesium alloys. It is purchased in the form of a powder in sealed tins, because it easily absorbs moisture, and the container must be kept sealed except when the flux is actually in use. Appropriate sizes of container should be employed in order to avoid gradual contamination of the bulk of the flux. Sometimes the flux is used in the form of a paste with methylated spirit in approximately 50/50 proportions.

The weld stick has to be fluxed and maintained fluxed. This is attained by warming the stick carefully with the blow-pipe, taking up a tuft of flux from the container and allowing it to run back along the weld stick to form a glass-like coating. As the weld stick is consumed in welding it must be re-fluxed before the whole of the glazed portion is used.

From the general purpose point of view, it is evident that if inclusions of flux are to be avoided butt welding is practically the only form that will be a success. Parts are held in an appropriately designed jig to locate them in position. Flux is applied along the junction, preferably using the weld stick to spread an even continuous film. Alternatively, the paste can be employed, but it is again stressed that this should preferably be a methylated spirit mixture and that water should be avoided, although it is quite extensively employed in industry. They are first tacked together by welding at a number of points at regular intervals. During this tacking the flux spreads around the area of the tack. Generally, especially with sheet jobs, it is then advisable to hammer the assembly flat while it is still hot. After tacking, the job is reversed and fluxed on the reverse side. The butt weld can then be proceeded with, using a size of weld stick and properly adjusted flame to give good penetration. Correct size of weld stick is strongly emphasised, and the natural inclination will be to use the smallest size so as to cause the minimum size of bead and in turn the least subsequent effort in cleaning up excess metal. These factors, however, must be made subservient to the assurance of full penetration along the whole of the junction, which must be regarded as criterion number one. Again, to assist in uniformity of the join in all respects, in working closely to the right heat, in driving the flux uniformly and minimising attack upon surfaces where it is not required, jigs can be copper-faced to assist in heat dissipation, but must be so constructed to present the job to the weld stick in a symmetrical fashion relative to the junction. To illustrate this for clarity, in edge-welding two panels at right angles, the junction should be horizontal and each face slope away at an angle of 45°. Washing must be executed as each weld is finished, otherwise corrosion starts, and once started it cannot be killed.

One satisfactory method of washing is to first rinse in hot flowing water to remove the bulk of the flux, then to scrub in water with a wire or stiff bristle brush and finish by a hot-water soak for about a quarter of an hour. The hot-water soak can advantageously contain 10 to 15% by weight of commercial potassium dichromate. Following this, a rinse in hot running water is given, followed by drying off. The chromate solution is preferably contained in an earthenware vat heated indirectly by an outer surrounding tank of boiling water, but galvanised iron can be employed. Some technicians prefer to include also an acid immersion treatment, in order to ensure removal of oxides and basic magnesium salts that may subsequently set up corrosion. Such a dip can be prepared from 1 vol. commercial nitric acid and 9 vols. of water, with sufficient potassium dichromate added (separately dissolved in a little hot water) to give a deep brown colour. A very short immersion period in this only is necessary (up to 2 mins.), and the process is applied after the preliminary scrubbing and prior to the long period soaking. The treatment is useful, though not regarded as essential as soaking if the scrubbing and washing operations are efficiently performed.

After machining welds to remove surplus metal, a further scrub in water and soak in the chromate solution may be resorted to as a safeguard against any tiny inclusions of flux revealed by the machining. When all the welds have been completed, the work should be passed through one of the regular chromate finishing processes in order to restore the protective film and safeguard the work for lying around the shops awaiting subsequent operations. There are many such treatments established, most of them patented and operated under licence from the magnesium

suppliers. A typical rapid one is the RAE half-hour process, which comprises immersion in the following solution at boiling point :—

Ammonium dichromate	1·5% by weight.
Potassium dichromate	1·5% ,,
Ammonium sulphate	3·0% ,,
0·880 ammonia	0·5% ,,

The solution is used in an aluminium container and treatment is followed by rinsing in running hot water and dying in air or in an oven at 60° C.

It will be seen that the processes for the removal of the corrosive chemical fluxes from magnesium alloys after welding are very simple, although elaborated from the labour view-point, and extended with respect to time. These are, however, unavoidable essentials, imposed by the highly reactive nature of the metal with which one is dealing. The ease with which the processes can be conducted is enhanced out of all proportion to the effort of taking the precautions already stressed—viz., those of minimum flux, proper design, no pockets, and rapidity of cleaning immediately after welding.

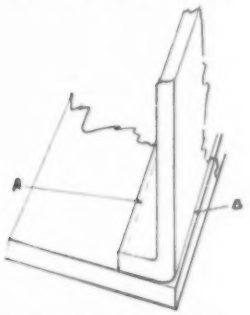


Fig. 1.—Wrong design for weld—with overlap.

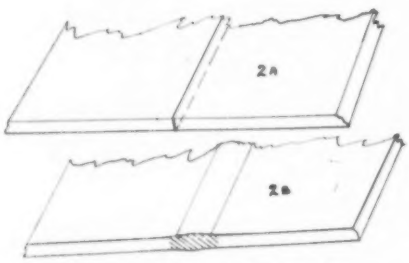


Fig. 2.—Correct design for weld—square butt joint.

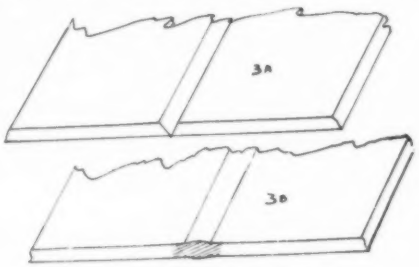


Fig. 3.—Correct design for weld—chamfered butt joint.

An overlap or anything akin to it is wrong. Fig. 1 demonstrates this and shows that welding must be done along the edge B or the edge A, or both. In the first two cases full strength is not secured, and flux is driven into the seam, becoming impossible to remove, but is retained. In the third case it is sealed in with equally disastrous results from the corrosion viewpoint. Fig. 2 shows the correct arrangement for sheet-work up to $\frac{3}{32}$ in. thickness (*a*) showing positioning of the two edges closely and squarely, and (*b*) the resultant weld ready for machining off, if necessary. For greater thicknesses, chamfering is necessary, as shown in Fig. 3 (*a*) and (*b*). Even when edge-welding a sheet to the surface of another, the overlap effect of welding along both sides of the edge of the sheet cannot be tolerated. Design should permit of the incorporation of a T-section, as shown in Fig. 4.

In dealing with castings and forgings, rods and sections, the same principles apply, and fabrication must be designed with respect to bevels or chamfers, and disposition of the two parts in jigs, to achieve welding to the best advantage.

A study of Fig. 5, which shows the electromotive series of the metals in terms of comparative voltages for single normal electrode combinations, establishes the unique position of magnesium. Not only does it stand high above all other metals of engineering construction on the electro-positive side of the series, but also it does not form a self-healing, tenacious and protective oxide covering film in the same way as does aluminium, which is next in the series. Consequently, there is nothing to prevent corrosion once the conditions are present for it to start, and anything in the nature of a bimetallic contact will hasten deterioration. For this reason, care should be taken to see that weld rods are approximately of the same composition as the base material. Also, inserts of steel, and especially of brass, copper and nickel-silver (that is, screws, rivets, bolts, springs, etc.) must be avoided as far as possible. If they must be used, aluminium or aluminium alloys (free from copper) should be chosen when suitable, with zinc-plated steel as the next best alternative. However, these items must not be present at the welding stage, otherwise bimetallic action sets up during the lengthy immersions of washing, with either destructive influences or at least heavy local pitting.

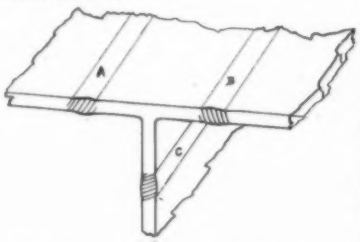


Fig. 4.—Correct design for edge to surface weld—use of T-section with three butt welds.

In the foregoing, the important subject of magnesium weld washing has been dealt with briefly, and of necessity the features considered have overlapped into some of the other phases of the welding process. Remarks in these directions have been strictly limited in scope to stress only the underlying principles that advantageously or adversely influence the flux problem, and the mechanical strength and corrodibility of the welded junctions.

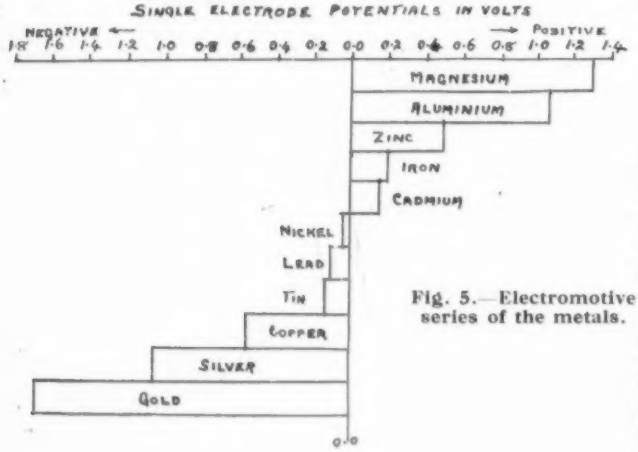


Fig. 5.—Electromotive series of the metals.

Aluminium Information Bureau

The Aluminium Information Bureau has removed to new premises at 109, Jermyn Street, London, S.W. 1. (Telephone : Whitehall 5411.)

The technical and advisory services of the Bureau will, as hitherto, be available to deal with problems submitted concerning the working, treatment and application of aluminium and its alloys.

Messrs. Londex, Ltd., of Anerley Road, London, S.E. 20, electrical remote control engineers and manufacturers, have issued a new leaflet giving information concerning their liquid level control system, " Lectralevel." Particulars are also given of the new Londex flow remote indicator and of the Londex automatic liquid level control.

The Relation Between Atomic Arrangement and Coercivity in an Alloy of Iron and Platinum

A state of very high coercivity can be produced in an alloy containing equal atomic proportions of iron and platinum, and an investigation is described which was undertaken in order to see if the atomic arrangement in the alloy could produce any explanation of this in the light of recent magnetic theory.

GRAF and Kussmann,[1] in an investigation of the iron-platinum system, stated that the coercivity can attain extraordinarily high values for the composition corresponding to equal atomic proportions of the two elements. For instance, quenching from 1,100° C. produced a coercivity of 1,540 gauss, which is more than double the value for the best magnet alloys of the Mishima[2] type. The phase diagram, however, does not lead to any obvious explanation of this remarkable fact, and recent work, described by Dr. H. Lipson, Dr. D. Shoenberg, and G. V. Stupart,* was undertaken in order to see if the atomic arrangement in the alloy could produce any explanation of this in the light of recent magnetic theory.

The alloy prepared gave an analysis on weight percentages as 23·4% iron and 76·3% platinum; equal atomic proportions would require 22·2% iron. The crystal structure of this alloy was found, by an X-ray powder photograph, to be ordered face-centred tetragonal of the same type as AuCu. Bulk specimens also were found to possess this structure for all heat-treatments, in contrast to the statements of previous workers that they would exist in two-phase form. At very high temperatures, however, it is probable that the alloy is face-centred cubic, though this state cannot be maintained by quenching.

The coercivity was determined as the magnetic field required to reduce the magnetic moment of the specimen to zero after it had been magnetised nearly to saturation in the reverse direction in the field of 15,000 gauss. The alloy obtained from the melt had a high coercivity, but when it was annealed for one day at 1,300° C. to remove possible coring, its coercivity fell to a small value. An attempt to reproduce Graf and Kussmann's result of a very high coercivity on quenching from 1,100° C. also gave a low value, and it was found later that much higher temperatures were needed. These temperatures proved too high for accurate measurement, and thus the heat-treatments are not described precisely. Very rough estimations of the cooling rates were obtained by noting the times required to reach a dull red heat, and these are incorporated in a table.

The highest coercivity produced was of the order of 1,200 gauss, and the lowest of the order of 150 gauss; these two states were found to be associated with characteristic microstructure. The microstructure of the state of high coercivity shows crystal grains crossed by sets of parallel bands, and these are interpreted as twinning bands, due to the breakdown of the high temperature cubic form.

In their discussion of the results of this investigation, the authors point out that the mechanism of formation of the tetragonal structure seems to be fairly well indicated by the experiments made. Above a certain temperature, which is given as 1,250° C. by Hansen[6] from the data of Isaac and Tammann,[7] but which the present authors believe to be considerably higher, the alloy exists in the disordered face-centred cubic state. When it reaches the transition temperature ordering occurs and the structure becomes tetragonal. There are, however, three different possible orientations for the tetragonal structure since any of the three cube edges may become the four-fold axis. In any cubic crystal the transition will probably take place in different directions in different parts, and planes, the traces of which are seen in the microphotographs, will be planes along which these parts join. There will, however, be other junctions of a more irregular character, where the twinning plane changes from (110) to, say, (1$\bar{1}$0).

This mechanism has been proposed before, by Dehlinger for AuCu[8] and by Jones and Sykes for Cu_3Pd,[9] for example, without any direct experimental evidence for it being given. The present authors have found that it can be shown very simply in the following way. A grazing incidence photograph was taken with the specimen oscillating through 15°. This showed spots lying on Debye-Scherrer lines corresponding to indices 001, 110, 111, 200, and 002. These last two lines are very close together, and it was noticed that the pattern of spots was the same in each. Since the two planes are at right angles to each other they could not possibly both reflect within 15° of each other in the same crystal; hence it follows that neighbouring crystals must be at right angles to each other.

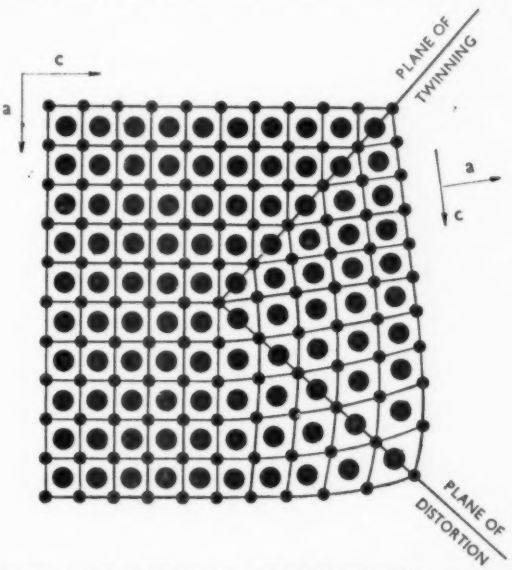


Diagram showing distortion of FePt lattice due to twinning.

The only reasonable explanation for this type of related orientations is that the tetragonal crystals are derived from a common cubic crystal. Since the axial ratio differs from unity it is impossible for the cubic crystal to break up into related tetragonal structures without a great deal of strain. The origin of this strain is shown in the accompanying illustration, which represents the atomic arrangement in the (100) plane, the difference between the axes being exaggerated for clarity. The section of the plane of twinning is shown from one corner to the centre of the diagram, and the distortion resulting from the attempt of the lattice to be continuous over the plane perpendicular to the plane of twinning is clearly seen. This, then, provides a certain amount of support for Becker's[10] theory, which suggests that the coercivity is proportional to the strain irregularities and to magnetostriction; Since the origins of the strains are clear enough, it was thought of interest to see whether the magnetostriction were unusually

* H. Lipson, D. Shoenberg and G. V. Stupart. *J. Inst. Metals*, 1941, **67**, Part II, 333.

1 L. Graf and A. Kussmann. *Physikal. Z.*, 1935, **36**, 541.
2 T. Mishima. *Stahl u. Eisen*, 1933, **53**, 79.
6 M. Hansen. "Der Aufbau der Zweistofflegierungen." Berlin: 1936, p. 718.
7 E. Isaac and G. Tammann. *Z. anorg. Chem.*, 1907, **55**, 63.

high. By means of an apparatus similar to that described by Webster,[11] a rough measurement of the magnetostriction was made for a specimen in the form of a thin plate, 13·5 mm. long. At the highest field available, 1,800 gauss, the magnetostriction was very small, $\delta l/l$ being an expansion of only about $1{\cdot}5 \times 10^{-6}$ (cf.—$40^{-6} \times 10$ for nickel); for this field, however, the specimen was magnetised to only about one-third of saturation, so it is possible that the magnetostriction for saturation is much higher. The small value may also be due, as in polycrystalline iron, to compensating effects in different crystal directions. For satisfactory magnetostriction results single crystals and much higher fields would be necessary; and to obtain any more detailed correlation of the high coercivity with the structure of the alloy, an estimate of the order of magnitude of the strain irregularities would also be necessary.

This work is being continued by an examination of the alloy CoPt. Preliminary results obtained by Mr. W. F. Cox show that the equilibrium structure is also tetragonal, but that the cubic high-temperature form can be maintained by quenching from about 900° C. Thus the heat-treatment required to produce high coercivities should be more easily controllable. A coercivity of 2,000 gauss has already been attained.

8 U. Dehlinger and L. Graf. *Z. Physik*, 1930, **64**, 359.
9 F. W. Jones and C. Sykes. *J. Inst. Metals*, 1939, **65**, 419.
10 R. Becker. *Z. Physik*, 1930, **62**, 253; and *Proc. Phys. Soc.*, 1940, **52**, 138.
11 W. L. Webster. *Proc. Roy. Soc.*, 1925, [A], **109**, 570.

Reviews of Current Literature

Researches on the Structure of Alloys

DURING more than fifteen years, Dr. W. Hume-Rothery has been responsible for a remarkable series of researches on metallic alloys carried out in the laboratories of the University of Oxford. This work has been directed mainly to the establishment of the general principles which decide (1) whether and in what proportions two or more metals are capable of forming solid solutions, (2) the structural and equilibrium characteristics of alloy systems, and (3) the properties of alloys. These are in fact the general principles of physical metallurgy.

Unlike the chemical industry, which to-day is a large-scale development of previous laboratory research developed *after* the main principles of chemistry had been established, the developments of physical metallurgy, until comparatively recent times, has been based on traditional practices handed down through the ages. During recent years scientific methods and research work have been used, but the research work has been largely confined to metals and alloys which appeared of immediate practical value. It is true that this work has often been supremely valuable in its own sphere, but its concentration on the practical alloys has prevented the metallurgist from seeing the general principles of physical metallurgy, since these principles are often revealed only by a study of uncommon metals and their alloys.

In the researches described in the present work, the deliberate aim has been to reveal the general principles, in the hope that, once these were grasped, the metallurgist would have such increased power that he might be considerably nearer to the stage at which he could make alloys with the properties which were desired.

The report is intended to describe briefly the progress which has been made to this end. The investigations it embraces cover the work described in about thirty papers. The importance of this work, apart from irs great scientific interest, lies in its promise of providing means for forecasting the properties of alloys from the atomic characteristics of the constituent metals.

Although the author has been more concerned to set out the plan, aims and main conclusions of the work done, than to give the detailed results which are published elsewhere, he has found it possible to indicate broadly the experimental results obtained and the evidence on which his conclusions rest. The author's work is of fundamental importance to metallurgists, physicists, and chemists, and the present report is especially useful as a summary.

By W. Hume-Rothery, M.A., D.Sc., F.R.S.; published by the British Non-Ferrous Metals Research Association as Research Report R.R.A. 562 (June, 1941, 21 pp.). It is obtainable from this Association, Euston Street, London, N.W. 1, or from any bookseller, price 2s. 6d. (or 50 cents) post free.

Analysis of Aluminium and its Alloys

THE preliminary steps of solution and separation taken in the analysis of aluminium and aluminium alloys differ from the methods used for other metals, but, in general, the actual determinations are essentially the same. The property of dissolving readily, not only in certain acids, but also in alkali hydroxides, differentiates aluminium from most other metals. This property effects the necessary separations of the aluminium from several constituents, as, for example, copper or nickel, since these elements remain practically insoluble when the aluminium is dissolved in caustic solution. Sodium hydroxide, therefore, is useful for starting analyses involving the determination of these constituents, while for other determinations, such as for iron and manganese, acids are used to dissolve the sample, further treatments separate the element sought.

Under the present emergency conditions many who are called upon to carry out analyses of aluminium and aluminium alloys will experience difficulties, especially those whose previous experience has been concerned with other metals and alloys, and the methods described in this book will prove invaluable, particularly as they have been developed and standardised by the British Aluminium Co., Ltd. The present volume, of 187 pages, supersedes an early volume published by this company and considerably amplifies the data then published on the subject.

The rapid development of the aluminium industry has been accompanied by a steady increase in the variety of alloys, and by an improvement in the quality and uniformity of the metal produced. This has necessitated the evolution of new and improved methods of analysis. In the course of their long experience the British Aluminium Co. have standardised certain methods which have proved to be most suitable in service, and these are given in the present volume. Some of the processes described are original; the majority are modifications of older processes; but each has been carefully selected, refined and arranged to ensure accuracy and speed.

Since the publication of the first edition, new physico-chemical methods have been developed, and their introduction into industrial control laboratories has shown them to possess great advantages in respect of speed with, in many cases, little loss of accuracy. A new section has therefore been added to include descriptions of some photometric, spectro-chemical and polarographic methods of analysis, which have been tested. The original chemical methods have also been revised; certain of them have been omitted and replaced by new ones, while others have been modified in the light of developments.

The book is admirably produced and is offered without charge to chemists and metallurgists whose work involves the use of aluminium and its alloys and is obtainable from the publishers, the British Aluminium Co., Ltd., "Oakley Manor," Belle Vue, Shrewsbury, Shropshire.